Adaptive Modulation, Adaptive Coding, and Power Control for Fixed Cellular Broadband Wireless Systems†

Ehab Armanious, David D. Falconer, and Halim Yanikomeroglu
Broadband Communications and Wireless Systems (BCWS) Centre,
Department of Systems and Computer Engineering, Carleton University, Ottawa, Canada

Abstract - The wireless channel is characterized by large statistical variations, which results in wide variations in its response. If the system is designed to meet the worst conditions of the channel, the throughput will be very small and the efficiency will degrade. On the other hand, if the system is designed to track the channel variations, it will yield a larger throughput. In this work, we investigate the advantage of using adaptive modulation, adaptive coding, and power control to track the channel variations in broadband fixed wireless access system. When the channel condition improves, the system will select a larger constellation size for modulation and a suitable coding scheme. When the channel degrades due to fading, the system will resort to a smaller constellation size for modulation and a powerful coding scheme. This approach yields larger throughput than using fixed modulation all the time. Power control adds a relatively small improvement in the throughput when combined with adaptive modulation and adaptive coding.

I. INTRODUCTION

There has been a lot of interest in fixed wireless communication systems to deploy inexpensive and faster alternatives to current wire line systems [1], [2]. Several techniques were considered to improve the efficiency of the available bandwidth for mobile wireless communication systems. Variable rate QAM over Rayleigh fading channels for mobile wireless systems was investigated [3] and was shown to provide about 5-dB improvement in the performance for the given operating conditions. Babich [4] investigated the improvement in the performance when different combinations of adaptive modulation, adaptive coding, and power control are used with wireless mobile cellular systems. Adaptive modulation techniques over Nakagami-m fading channels were also investigated in [5] and [6] for mobile wireless channel.

In this work, we investigate the effect of using different combinations of adaptive modulation, adaptive coding, and power control to increase the throughput of fixed cellular broadband wireless systems. The downlink direction is considered for simulation since data rates are likely to be larger in this direction for these systems. A modulation level (QPSK, 16-QAM, or 64-QAM) will be selected to match the current conditions of the channel for each transmission. Error-free feedback information will be used to inform the transmitter about the current channel condition. The effect of combining Bit-Interleaved Coded Modulation (BICM) [7] with adaptive modulation on the system performance will be examined. Reference [7] shows that BICM has good performance when utilized for fading channels. Power control, i.e. adjusting the transmitted power to meet the required SINR at the receiver, will be examined with adaptive modulation and adaptive coding.

The remainder of this paper is organized as follows. The system model is presented in Section II. Section III explains the simulation results. The results are summarized in section IV.

† This work was supported by the Canadian Institute for Telecommunication Research (CITR).

II. THE SYSTEM MODEL

Two system models were used for the simulation, as shown in Fig. 1.

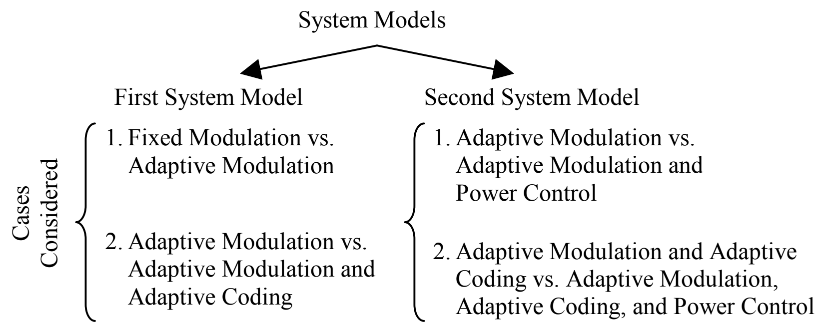

Fig. 1: System Models and the Compared Cases

The first system model is used to evaluate two different cases: The first case involves comparing a system using adaptive modulation versus a system that uses fixed modulation (QPSK, 16-QAM, or 64-QAM). The second case compares a system that uses adaptive modulation versus another system that uses combined adaptive modulation and adaptive bit-interleaved coded modulation. The first system model consists of 9 cells in a square grid as shown in Fig. 2. Each cell is divided into four sectors. It is assumed that each sector is served by a base station with an ideal 90^{o} beamwidth antenna, which has main lobe and side lobe gains of 15 dB and –10 dB, respectively. The available transmission bandwidth is used completely in each sector. Utilizing perfect orthogonal polarization in adjacent sectors eliminates adjacent sector interference.

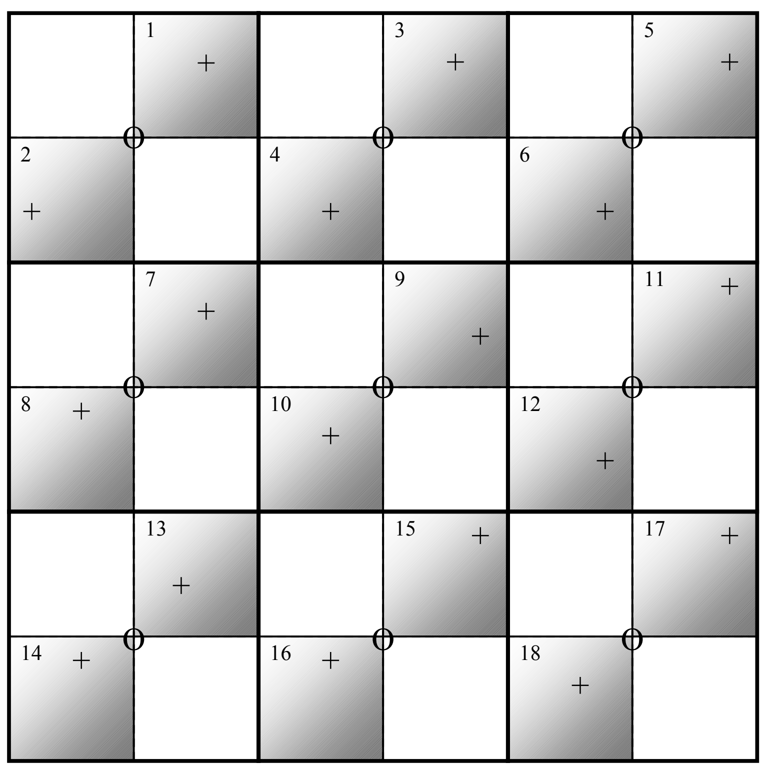

Fig. 2: First System Model

In Fig. 2, $\oplus$ denotes back-to-back sectored antennas, with 90^{o} beam width antenna, a main lobe gain of 15 dB, and side lobe gain of –10dB and + denotes all users in the same co-channel set.

Adjacent channel interference is not taken into account. A loaded TDMA system is considered where there is one user from the same co-channel set in each sector that utilizes a particular type of polarization (see Fig. 2). The user of interest is located in sector # 10 and surrounded by 17 interferers. The shadowed areas mark the sectors for the user of interest and the corresponding interferers. The user, and all the interferers with similar polarization, will be positioned randomly, with uniform distribution, in each sector.

Since increasing the throughput in the downlink is one of the major goals to improve the performance, the throughput in the downlink will be examined by varying several performance metrics, one metric at a time. In fixed wireless systems, the users and the base stations will use sectored antennas. The users' antennas will be positioned in such a way to achieve line-of-sight communications, if possible. The dominant interferer, according to this setup, will be from the side lobe of the sectored antenna in the opposite sector, namely sector # 9. The transmitted signal from sectored antenna # 10 will be amplified by the main lobe gains of the base station's and the user's antennas. The interfering signal, from the dominate interferer, will be attenuated by the side lobe gain of the sectored antenna # 9 and amplified by the main lobe gain of user's antenna.

The second system model (see Fig. 1) uses the first system model as a building block. The first system model is repeated 9 times to form 3 rows by 3 columns containing a total of $9\times36 = 324$ sectors. The new model will form a 5-tier cellular system. This model is used in two cases related to power control. The first case involves comparing a system that uses adaptive modulation versus another system that uses adaptive modulation and power control. The second case compares a system that uses adaptive modulation and adaptive bit-interleaved coded modulation versus another system that uses adaptive modulation, adaptive bit-interleaved coded modulation, and power control. The first tier is the inner most cell. The performance metric is based on the user of interest that is located in the lower left sector of the first tier. It is also assumed that the second system model uses orthogonal frequency polarization and the system is fully loaded.

III. THE SIMULATION RESULTS

The underlying assumptions for the simulation as well as the simulation results are presented in this section. The common assumptions to all simulations are as follows:
The simulation is carried out for downlink transmission, carrier frequency =2.5 GHz, BER =10^{-5}, transmission bandwidth =6 MHz, maximum transmitted power =200 mW, propagation exponent for the user of interest and all the interferers =4, standard deviation of log normal shadowing =7 dB, antenna beam width for the base station =90^{o}, antenna beam width for the user and all the interferers =30^{o}, antenna gains for the base station, the user of interest, and all the interferers: main lobe =15 dB, side lobes =-10 dB, the Rician parameter, k, for the user of interest and the dominant interferer = 8, and Rician parameter for the remaining interferers = 3. Macro-diversity is not used in the simulations, i.e. each user communicates with the nearest BS. Furthermore, we assume that the channel variations are tracked precisely. At each snapshot the channel is estimated perfectly, and the parameters are adjusted accordingly.

The metric for evaluating the system performance is the effective average modulation efficiency; defined as the number of correctly received bits/sec for each Hz of the available bandwidth for the user of interest, or bits/sec/Hz. For example, when the base station utilizes a fixed modulation size of 16QAM, radio frames will be modulated and transmitted accordingly. The user, at the receiving side, will estimate the received SINR and compare it with the threshold SINR required to achieve a BER of 10^{-5} for an AWGN channel and 16QAM, assuming that interference plus noise have a gaussian distribution. If the estimated SINR is less than the threshold SINR, the whole frame will be discarded and the modulation efficiency will be 0 bits/sec/Hz for this frame. On the other hand, if the estimated SINR is equal to or larger than the threshold SINR, the modulation efficiency will be 4 bits/sec/Hz for this frame. The modulation efficiency is averaged over several thousand frames to obtain the effective average modulation efficiency.

Fig. 3 shows the effective average modulation efficiency with respect to the user of interest's distance from the base station, for fixed and adaptive modulation. The results show that any fixed modulation will yield a throughput below the maximum possible value even near the base station. For example the maximum possible throughput is 4 bits/sec/Hz for 16-QAM. The effective average modulation efficiency for 16-QAM near the base station is about 2.8 bits/sec/Hz. The degradation is due to the presence of the dominant interferer (based on our fully loaded system) as well as the statistical variations that are introduced by Rician fading channel.
The results also show that adaptive modulation provides a gain of about 1.3 bits/sec/Hz near the base station compared to the best possible constellation size, which is 16-QAM at this location. However, if the user is located farther from the base station, this gain will decrease. If the user is located near the edge of the sector, the effective average modulation efficiency for adaptive modulation will be slightly better than the best performing constellation size, which is QPSK in this case. Therefore, adaptive modulation outperforms any fixed modulation in the downlink direction of fixed cellular broadband wireless systems.

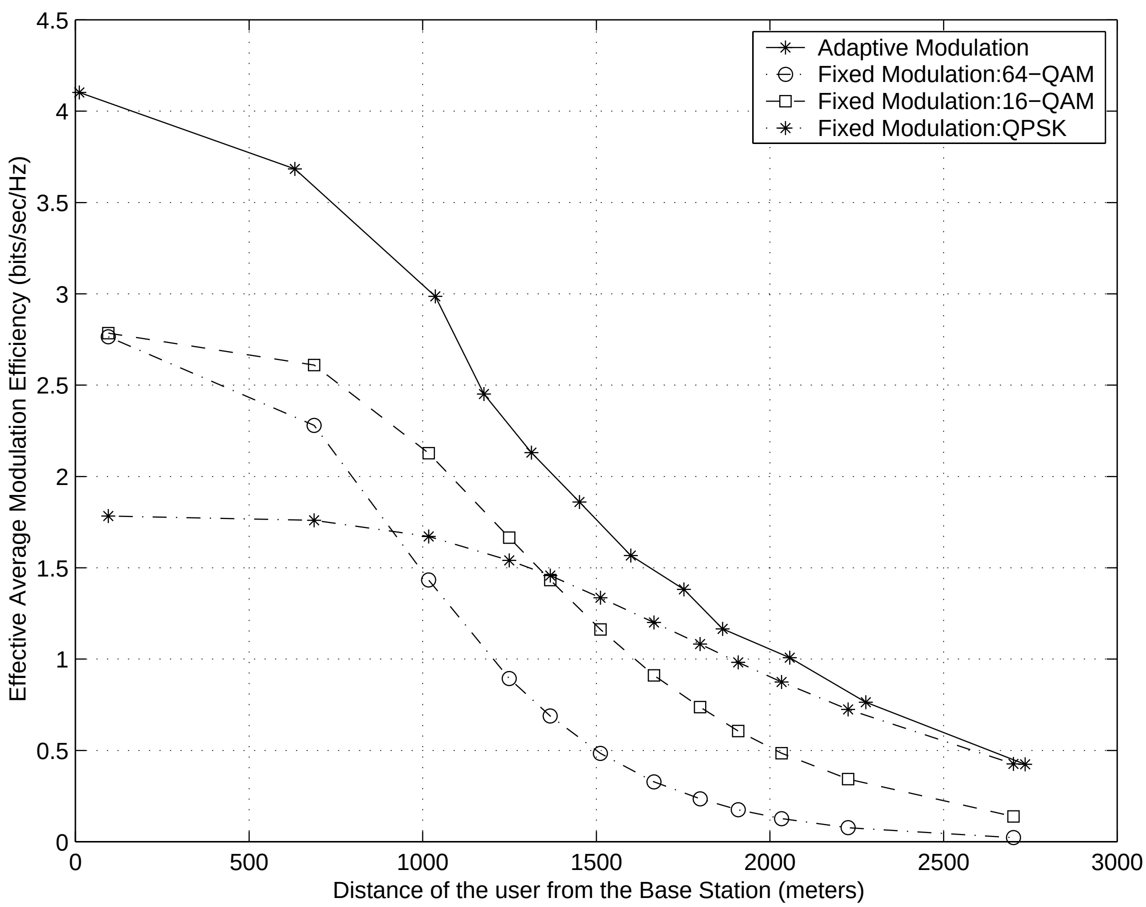

Fig. 3: The impact of using adaptive modulation on the system performance (no coding, no power control)

The effect of combining Bit Interleaved Coded Modulation (BICM) with adaptive modulation is shown in Fig. 4. The results were obtained from the simulations by assuming that interference plus noise had a gaussian distribution, and by making use of the results of static BICM simulations in additive white gaussian noise, with ideal interleaving. The codes were derived by optimally puncturing a convolutional code with constraint length 7 [8]. Bit Interleaved Coded Modulation, with code rates 1/2, 2/3, 3/4, and 7/8 were used with adaptive modulation in four different simulations. Also the case of adaptive coding and adaptive modulation was examined, i.e. all the possible combinations of QPSK, 16QAM, and 64QAM; with code rates 1/2, 2/3, 3/4, and 7/8 were examined. The results show that near the base station adaptive modulation and code rate 7/8 were the best combination compared with adaptive modulation and code rates 1/2, 2/3, 3/4, and adaptive modulation without coding. Near the edge of the sector adaptive modulation and code rate 1/2 were slightly better than the remaining combinations. When adaptive BICM is combined with adaptive modulations, the performance was found to be better than the best performing coding rate almost everywhere in the sector. The slight degradation in the performance of adaptive coding near the middle of the sector compared with adaptive modulation and coding rate of 7/8, is due to the statistical variations. The performance gained by combining adaptive modulation and adaptive coding, compared with adaptive modulation alone, is higher near the edge of the sector than near the base station.

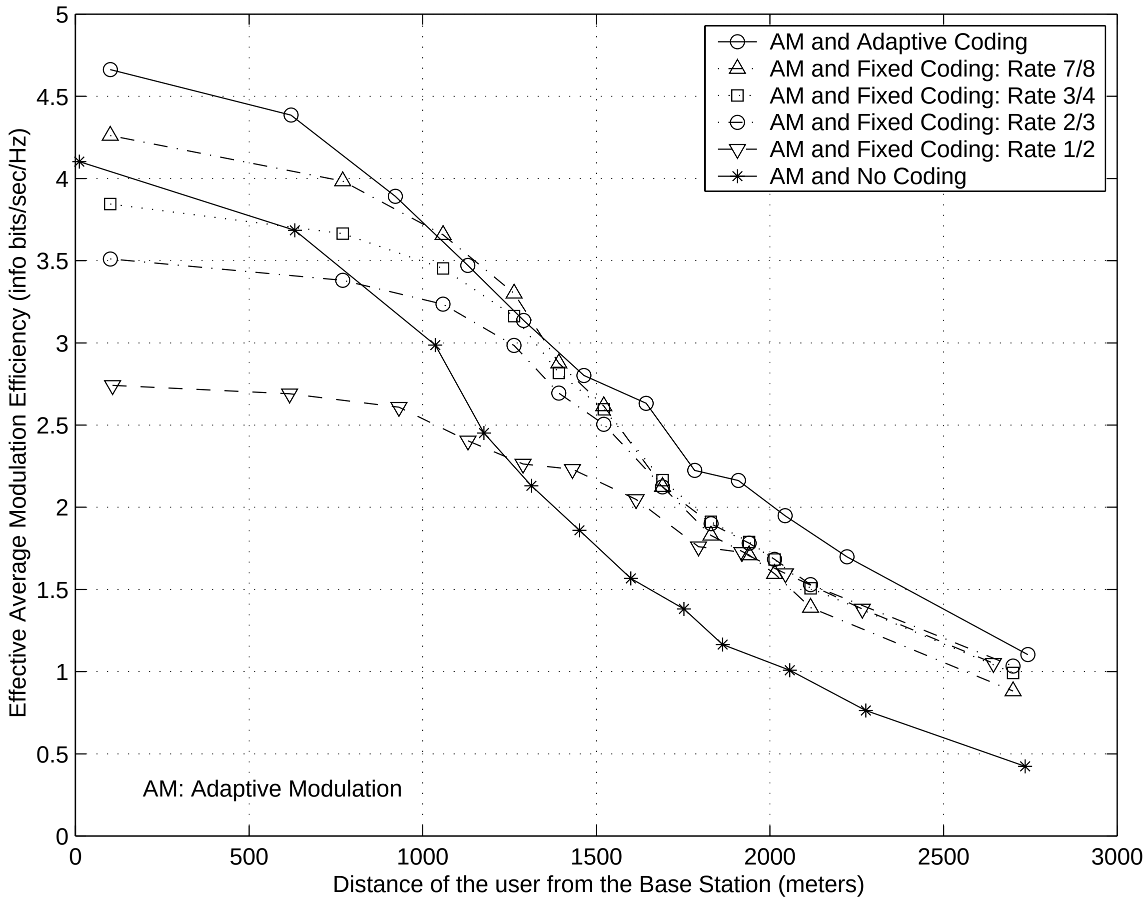

Fig. 4: The impact of using combined adaptive modulation and adaptive coding on the system performance (no power control)

The remaining part of this section is based on the second system model (see Fig. 1). When power control is used, the actual transmitted power is set to 1.1 of the required transmitted power, i.e. an extra 10% of the required power is transmitted as a safety margin.

Combining power control with adaptive modulation is examined in Fig. 5. The top part of the figure compares a system that uses adaptive modulation with another system that uses adaptive modulation with power control. The results show a performance gain throughout the sector on top of the gain provided by adaptive modulation alone. Similar to the performance gained by combining adaptive modulation and adaptive BICM, the gain of combining adaptive modulation with power control is slightly better near the edge of the sector than near the base station. Near the base station, power control with adaptive modulation provide performance gain of about 0.2 bits/sec/Hz. Near the edge of the sector this gain increases to 0.35 bits/sec/Hz.
The bottom part of Fig. 5 shows the average amount of the transmitted power from the base station. Using adaptive modulation alone will result in constant transmitted power. Combining adaptive modulation with power control will result in reduction in the transmitted power throughout the cell, with the largest reduction

being near the base station, about 80 mW on average, and the smallest reduction at the edge of the cell, about 10 mW on average.

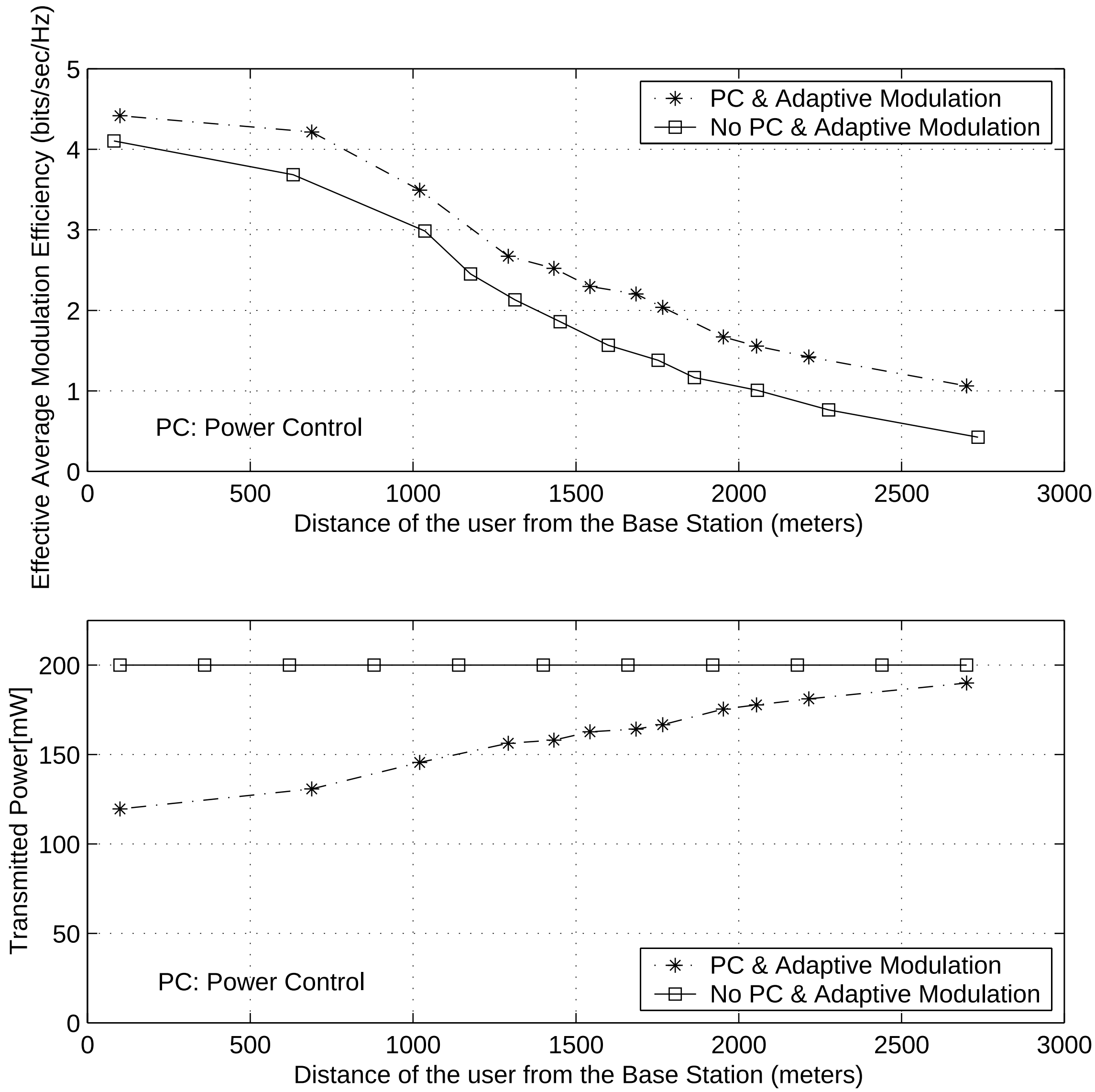

Fig. 5: The impact of using combined adaptive modulation and power control on the system performance (no coding)

The second case in the second system model (see Fig. 1) concerns the effect of combining power control with adaptive modulation and adaptive BICM. The results are shown in Fig. 6. The top part of the figure compares four system configurations: adaptive modulation, adaptive modulation and power control, adaptive modulation and adaptive BICM; and combined adaptive modulation, adaptive BICM, and power control. The results indicate that adaptive modulation and adaptive BICM outperforms adaptive modulation and power control throughout the sector. Furthermore, the performance gain obtained by combining adaptive modulation, adaptive BICM, and power control is minimal compared with the gain obtained by combining adaptive modulation and adaptive BICM.

The bottom part of Fig. 6 shows the average transmitted power, in mW. The results indicate that the average transmitted power, in the downlink direction, will increase throughout the sector when power control is combined with adaptive modulation and adaptive BICM compared with the case of using adaptive modulation and power control. However, the transmitted power in this case is well below the maximum value near the base station, and levels off below the maximum transmitted power near the edge of the sector.

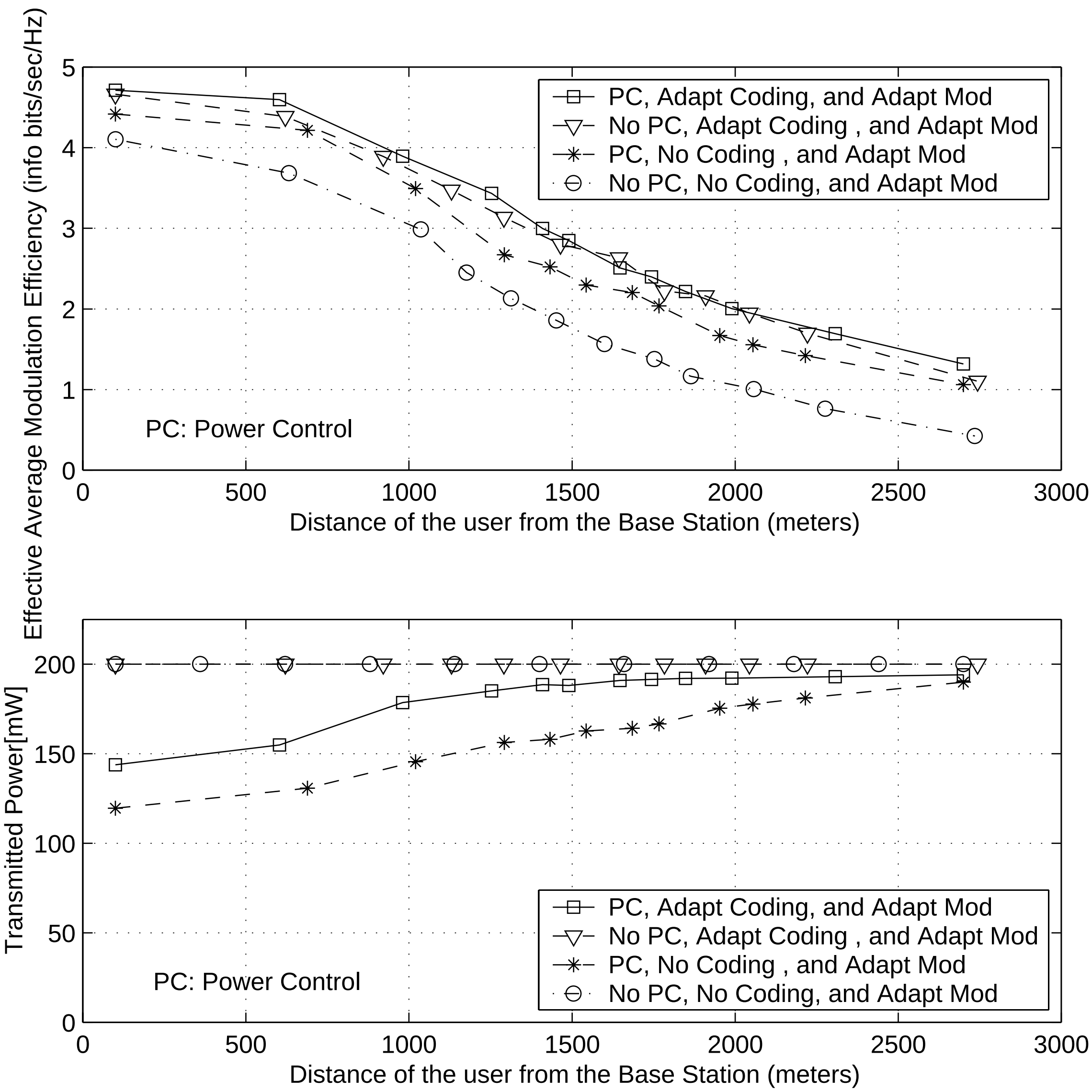

Fig. 6: The impact of using combined adaptive modulation, power control, and adaptive coding on the system performance

IV. CONCLUSIONS

In this work several techniques were investigated to improve the performance, i.e. the throughput, in the downlink direction of fixed broadband cellular wireless systems. The results are summarized as follows:

a) Adaptive modulation was shown to provide performance gain throughout the sector.
b) Combining adaptive coding, based on BICM, with adaptive modulation provides an extra gain on top of the gain that was obtained with adaptive modulation without coding, case (a). Users near the edge of the sector experience higher performance gain than those near the base station.
c) Combining power control with adaptive modulation provides performance gain similar to, but less than, the previous case.

d) Minimal performance gain, on top of the gain provided by case (b), is obtained when power control is combined with adaptive modulation and adaptive coding. The gain provided by this case does not justify the complexity of combining the three techniques together. Therefore, no need for using power control with adaptive modulation and adaptive coding. The later two techniques are enough to provide an optimum performance in this setting.

ACKNOWLEDGMENT

The simulation results for Bit-Interleaved Coded Modulation were kindly provided by Dr. Sirikiat Lek Ariyavisitakul, Home Wireless Networks, Norcross, GA, USA.

REFERENCES

[1] K. V. Ravi and P. Soma, "Analysis and modeling of local multipoint distribution service (LMDS) channel," *IEEE GLOBECOM'99*, pp. 873-877, Dec 1999.

[2] D. A. Gray, "A broadband wireless access system at 28 GHz," *IEEE Wireless Comm. Conf*., pp. 1-7, Aug. 1997.

[3] W. T. Webb and R. Steel, "Variable rate QAM for mobile radio," *IEEE Trans. Comm*., vol 43, No. 7, pp. 2223-2230, July 1995

[4] F. Babich, "Considerations on adaptive techniques for time-division multiplexing radio systems," *IEEE Trans. Veh. Technol*., vol. 48, No. 6, pp. 1862-1873, Nov. 1999.

[5] M. S. Alouini and A. Goldsmith," Capacity of Nakagami multipath fading channels," *IEEE Proc. VTC'97*, vol. 1, pp. 358-362, May 1997.

[6] M. S. Alouini, X. Tang, and A. Goldsmith, "An adaptive modulation scheme for simultaneous voice and data transmission over fading channels," *IEEE Proc. VTC'98*, vol. 2, pp.939-943, May 1998.

[7] G. Cair, G. Taricco, and E. Biglieri, "Bit-interleaved coded modulation," *IEEE Trans. Info. Theory*, vol. 44, No.3, pp. 927-946, May1998.

[8] Y. Yasuda, K. Kashiki and Y. Hirata, "High Rate Punctured Convolutional Codes for Soft Decision Viterbi Decoding", *IEEE Trans. Comm*., Vol. COM-32, No. 3, pp. 315-319, Mar. 1984.