Adaptive Modulation, Adaptive Coding, and Power Control for Fixed Cellular Broadband Wireless Systems: Some New Insights[1]

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
E-mail: {earmanio, ddf, halim}@sce.carleton.ca

***Abstract*—It is well known that link adaptation techniques, when designed to track the channel variations, yield a higher network throughput. In this work, we investigate the throughput returns due to the employments of various combinations of adaptive modulation, adaptive coding, and adaptive power control in a fixed cellular broadband wireless access system incorporating the effects of shadowing, multipath fading, and multiple access interference. The system considered is Multipoint Multichannel Distribution System (MMDS) with carrier frequency 2.5 GHz. It is observed that among all the possible combinations, the combination of adaptive modulation and adaptive coding (without power control) is the most efficient type since the further employment of adaptive power control only adds a relatively small improvement in the throughput. The frequency of occurrence of different constellation sizes and code rates with the percentages of the successful and failing links, are reported as well in this study.**

Keywords – link adaptation, adaptive modulation and coding; power control; fixed cellular networks, broadband wireless access.

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 [2] 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 throughput returns due to using different combinations of adaptive modulation, adaptive coding, and adaptive power control in a broadband fixed wireless cellular system. The effect of shadowing, Multipath fading, and multiple access interference are incorporated in the system. The downlink direction is considered for simulation since data rates are likely to be larger in this direction for these systems. Error-free feedback information will be used to inform the transmitter about the current channel condition. When adaptive modulation is used, a constellation size (QPSK, 16-QAM, or 64-QAM) will be selected to track the current conditions of the channel for each transmission. 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. Adaptive 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.

II. THE SYSTEM MODEL

A comprehensive spectral efficiency analysis with respect to fixed modulation (FM), adaptive modulation (AM), adaptive coding (AC), and power control (PC) is shown in Table 1.

Table 1: Comprehensive Spectral Efficiency Analysis With Respect to FM, AM, AC, and PC.

	Compared Techniches			
System Type I	FM	AM		
		AM	AM, AC	
System Type II		AM	AM, PC	
			AM, AC	AM, AC, PC

System type I is used to evaluate two different cases: The first case involves comparing a system using fixed modulation (QPSK, 16-QAM, or 64-QAM) versus a system that uses adaptive modulation. The second case compares a system that uses adaptive modulation versus another system that uses combined adaptive modulation and adaptive bit-interleaved coded modulation. System type I consists of 9 cells in a square grid as shown in Fig. 1. Each cell is divided into four sectors.

[1] This work was supported by the Canadian Institute for Telecommunication Research (CITR).

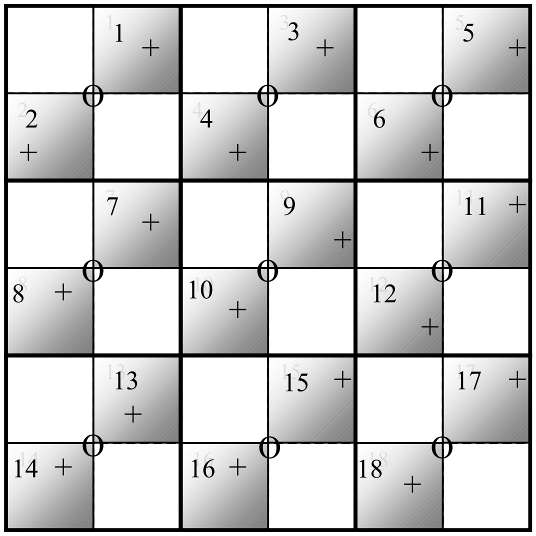

Fig. 1: System Type I

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. A non line of sight system is assumed to simulate the actual possible operation.

System type II (see Table 1) uses system type I as a building block. System type I is repeated 9 times to form 3 rows by 3 columns containing a total of 9×36 = 324 sectors. The new type will form a 5-tier cellular system. This type 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.

In Fig. 1, ⨁ denotes back-to-back sectored antennas, with 90^o beam width, a main lobe gain of 15 dB, and side lobe gain of –10dB. The symbol + 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. 1). The user of interest is located in sector # 10 and is surrounded by 17 interferers. The shadowed areas mark the sectors where the user's terminal of interest and the corresponding interfering terminals are located. The user's terminal, and all interfering terminals with similar polarization, will be positioned randomly, with uniform distribution, in their sectors.

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 dominant 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.

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 16-QAM, radio frames will be modulated and transmitted accordingly. The user, at the receiving side, will estimate the received SINR and compare it with the SINR threshold that is required to achieve a BER of 10^{-5} for an AWGN channel and 16-QAM, assuming that interference plus noise have a Gaussian distribution. If the estimated SINR is less than the threshold SINR, the entire 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 SINR threshold, the modulation efficiency will be 4

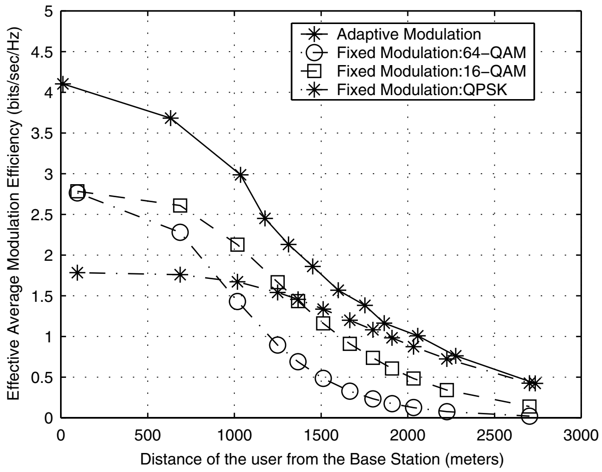

Fig. 2: The impact of using adaptive modulation on the system performance (no coding, no power control)

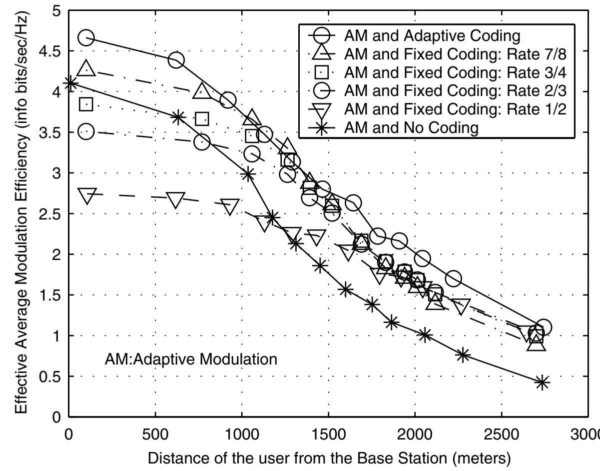

Fig. 3: The impact of using adaptive modulation and adaptive coding on the system performance (no power control)

bits/sec/Hz for this frame. The modulation efficiency is averaged over several thousand frames to obtain the effective average modulation efficiency.

Fig. 2 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.

The effect of combining Bit Interleaved Coded Modulation (BICM) with adaptive modulation is shown in Fig 3. 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 bit error rate 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, 16-QAM, and 64-QAM; 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.

Figures 4, 5 and 6 show the percentage of usage for each combination of code rate and modulation at three locations in the sector when adaptive coding is combined with adaptive modulation. A user equipment located at 100 meters form the base station will use combinations of code rate and modulation as shown in Fig. 4. Since the link quality is good at this location, 64-QAM without coding is used almost 45% of the time. Combinations of coding and 64-QAM are used more often compared with combinations of coding and 16-QAM or QPSK. If the user equipment is located near the middle of the sector, as shown in Fig. 5, combinations of higher code rates and smaller constellations for modulation will be used more often than near the base station. The link quality will degrade near the edge of the sector and the combinations of code rate and modulation will be as shown in Fig. 6. Low code rates with smaller constellation sizes will be used at this position. The percentage of successful links drop from 98.03% near the base station to 60.98% near the edge of the sector.

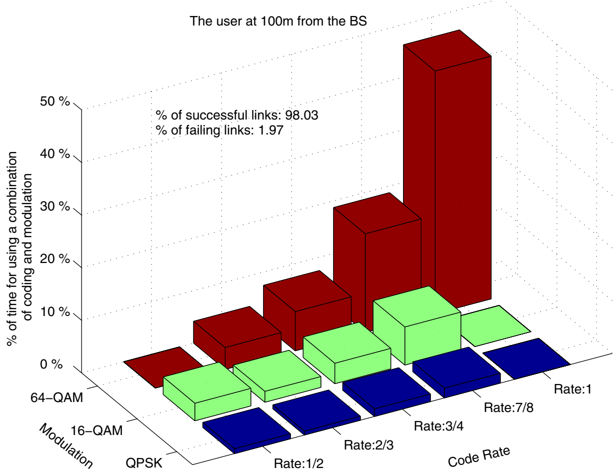

Fig. 4: Percentage of successful and failing links, 100 m from the base station

The remaining part of this section is based on the second system model (see Table 1). When power control is used, the actual transmitted power is set to 1.1 times 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. 7. 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. 7 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.

The second case in the second system model (see Table 1) concerns the effect of combining power control with adaptive modulation and adaptive BICM. The results are shown in Fig. 8. The top part of the figure compares a system with five different configurations: Fixed modulation using QPSK, 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

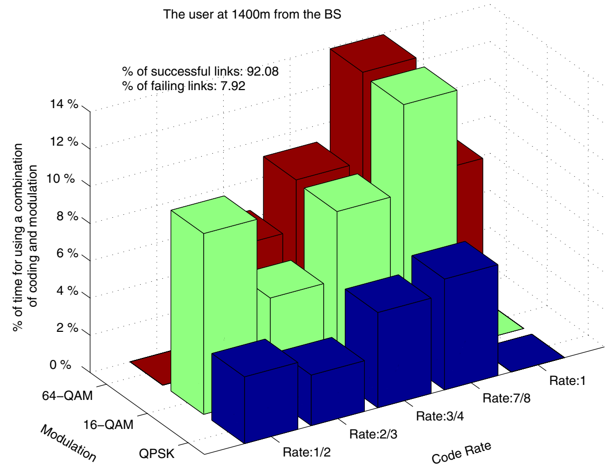

Fig. 5: Percentage of successful and failing links, 1400 m from the base station

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 figure also shows the potential advantage of using the adaptation techniques compared with a system that uses QPSK only. The bottom part of Fig. 8 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.

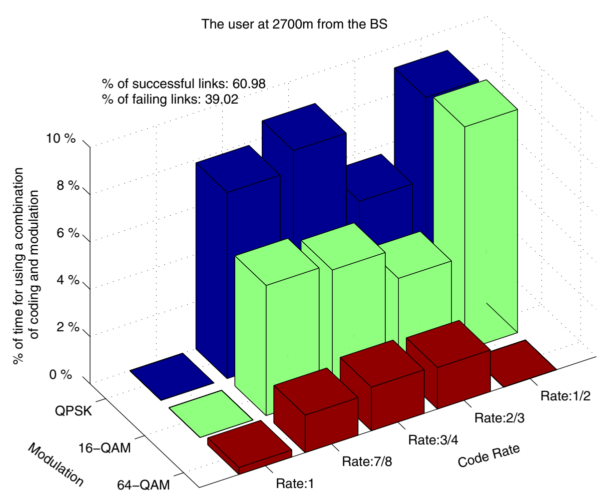

Fig. 6: Percentage of successful and failing links, 2700 m from the base station

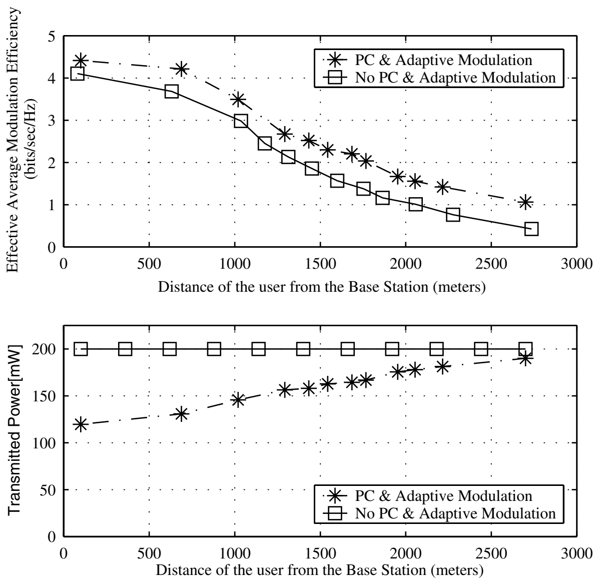

Fig. 7: The impact of using combined adaptive modulation and power control on the system performance (no coding)

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 may not justify the complexity of using power control with adaptive modulation and adaptive coding. The later two techniques are enough to provide an optimum performance in this setting.

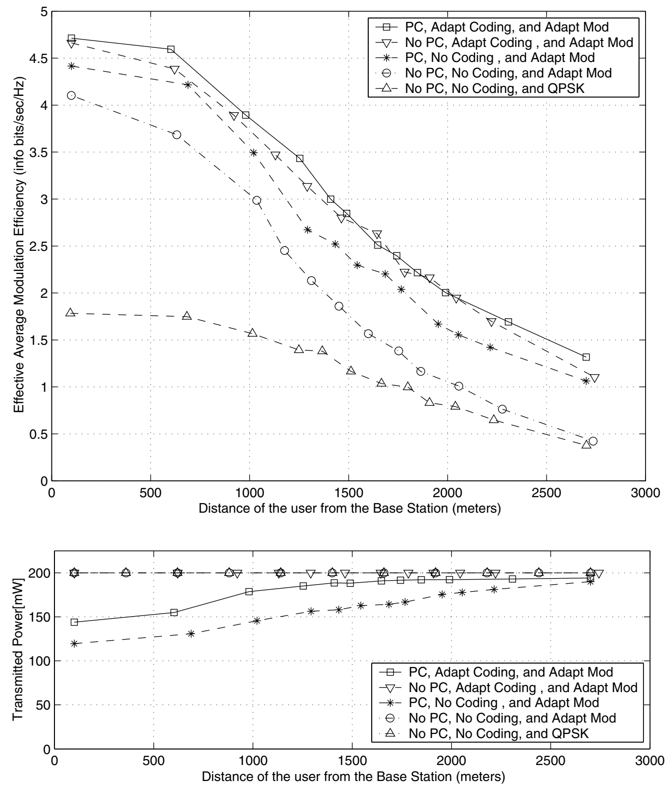

Fig. 8: The impact of using combined adaptive modulation, power control, and adaptive coding on the system performance

Acknowledgment

The static BER versus SNR performance curves for Bit-Interleaved Coded Modulation were kindly provided by Dr. Sirikiat Lek Ariyavisitakul, Radia Communications, 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. Vehic. 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, May 1998.
[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.