A Simulation Testbed for Radio Resource Management in Broadband Wireless Access*

Mohamed H. Ahmed, Halim Yanikomeroglu, Samy Mahmoud, and David Falconer
Broadband Communications and Wireless Systems (BCWS) Centre,
Dept. of Systems and Computer Eng., Carleton University,
Ottawa, Canada

***Abstract*- Radio resource management (RRM) plays a vital role in the Quality of Service (QoS) provisioning in wireless networks in general and in Broadband wireless access (BWA) in particular. A great deal of attention has been given to RRM schemes in mobile communication networks. However, BWA is inherently different in many aspects including the offered services, traffic models, QoS requirements, propagation characteristics, and network structure. In order to design, implement and/or explore the performance of radio resource management algorithms, a system level simulation tool has been designed as a testbed for RRM schemes in BWA. A MATLAB toolbox (*RUNE*) has been employed after we have modified many of its functions and introduced several new features. The simulation tool is so flexible and effective that new RRM schemes can be easily included, tested and analyzed.**

I. INTRODUCTION

There is a growing demand for broadband wireless access due to the increasing popularity of the Internet and multimedia services and the superiority of the fixed wireless access to other competitors such as xDSL, optical fibre and CATV.

Since Radio Resource Management (RRM) schemes have a significant impact on the Quality of Service (QoS) provisioning and the achievable performance of broadband wireless systems, it is crucial to have the necessary tools to analyze and investigate various RRM schemes. There are mainly three categories for such tools, namely, field measurements, analytical tools, and simulation tools. Field measurements can provide accurate results but require a considerable amount of effort and equipment. Analytical tools are useful but not always practical for complex systems. Simulation tools requires much less amount of effort and equipment than those needed for field measurements and can provide accurate results even with complex systems.

Various simulation tools for wireless application have been developed in the last two decades in both industry and academia. However, to the authors' best knowledge, there is not a simulation tool that can provide a flexible platform for the exploration of RRM schemes and their impact on the system performance in broadband wireless networks taking into account the system-level design parameters.

In this paper, a detailed description of a simulation testbed for BWA is discussed. The main modules of the simulation tool are described in the next section. Section III presents the simulation environment. Then, the results of some illustrative examples are presented in Section IV. Finally, summary and conclusions are given in section V.

II. SIMULATION TOOL DESCRIPTION

The simulation tool consists of five main modules as follows:

- The first one is the traffic module that generates traffic at both the session level and the packet level for the following services: voice, video, http (individual users), and http (from LANs).
- The second module is the channel and propagation module. Modern channel models such as Erceg's model, COST 231, and outdoor-to-indoor models are included.
- The third module includes the radio resource management schemes such as power control, call admission control, rate control using adaptive coding and modulation, channel allocation, scheduling, and BW reservation.
- The fourth module contains the sectorization and smart antennas.

* This work is supported by the National Capital Institute of Telecommunication (NCIT), Ottawa, Ontario, Canada

- Finally, the fifth module is the statistics collection including the QoS parameters and performance measure.

The simulation tool is time-driven with a step size (τ) which has to be small enough to follow fast variations such as the temporal multipath fading changes and packet handling dynamics.

The simulation tool has been built using a MATLAB toolbox (*RUNE*) developed by Magnus Almgren and Olav Queseth [1]. We have modified many of its functions and introduced several new features such as smart antennas at Basestation (BS) and (Subscriber Station) SS, modern channel and propagation models, multimedia traffic models, RRM schemes, and packet level handling (scheduling and buffer management).

The simulation tool has been built in a modular structure so that any module can be modified, added or even replaced without affecting other modules.

The simulation tool has been verified by simulating some simplified scenarios and comparing the simulation results with already known results (for example using analytical models). Then, more complex simulation scenarios have been used for verification by comparing the results of the simulation tool with already published results. For instance, Fig. 1 shows a comparison of the simulation tool results and previously published results [2] of the CDF(SIR) values in fixed wireless networks using different BS assignment policies.

III. SIMULATION ENVIRONMENT

The main aspects of the system model are as follows:

1. Traffic Models: Call (session) traffic is modeled by Poisson traffic with exponential call duration. The arrival rate of class i is λ_i, while the mean call duration is $1/\mu_i$. As shown in Fig. 2, during the call duration, packets are generated using n Interrupted Poisson Processes (IPP). The superposition of these n-IPP models the self-similar traffic of different multimedia sources [3].

2. Network Structure: A hexagonal cellular structure is considered with a wraparound structure. Each cell is divided into S sectors. Thus, an ideal beam pattern with a $(360/S)^o$-beamwidth, main lobe gain of $G_{BS\text{-}ML}$ dB, and side lobe gain of $GB_{BS\text{-}SL}$ dB is used at BSs. SSs have directional antennas with a θ^o-beamwidth, main lobe gain of $G_{SS\text{-}ML}$ dB, and side lobe gain of $G_{SS\text{-}SL}$ dB. Different beam patterns such as *sinc*-shaped or any other arbitrary patterns also can be included and used at the BSs and/or SSs. While the BS antenna beams are fixed, antenna beams at the SSs are pointing at the serving BS direction. Different frequency reuse plans can be used depending on the available spectrum, required signal quality and traffic loading. Also, both static and dynamic channel allocation can be employed. With sectorization, channels given to each cell can be further assigned to sectors or left available to all sectors in a common pool.

3. Propagation and Channel Models: Various channel models are available in the simulation tool such as the classical exponential pathloss model, Erceg's model [4], and Cost231 model [5]. These models are valid only for the SS rooftop antenna case. For the indoor antenna option, two more models are used to include the outdoor-to-indoor propagation effects [6], [7]. Lognormal shadowing with a standard deviation (σ) is employed in the channel model. Shadowing samples are spatially correlated. Multipath fading is modeled by Rayleigh distribution. Rayleigh fading samples are temporally correlated using a rounded (bell-shaped) Doppler spectrum having a 3-dB frequency of f_d with a range of a few Hz [7],[8]. The Rayleigh fading samples of a user from different BSs are mutually independent.

4. Multiple Access Scheme: Time is divided into frames with a frame duration (T) and N slots per frame in a TDMA fashion. OFDMA is also available where each user can be assigned a set of subcarriers. The number of assigned subcarriers to each user is determined by the RRM controller.

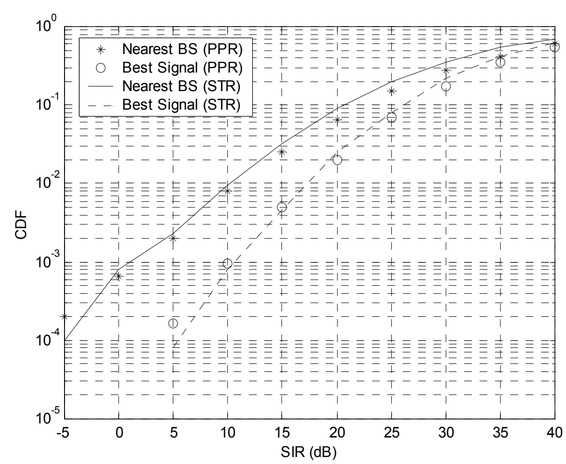

Fig. 1. CDF(SIR) of Previously Published Results (PPR) [2] and Simulation Tool Results (STR).

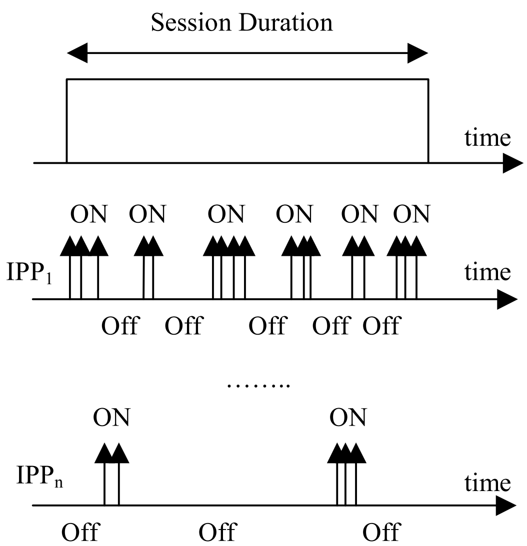

Fig. 2 Packet traffic model where IPP_1 represents the short term IPP component while IPP_n represents the long-term IPP component.

5. Radio Resource Management: As shown in Fig. 3, RRM is responsible for admitting new calls and directing them to the appropriate queue according to their class of service. RRM is also responsible for packet scheduling, power control and allocation, and rate control using adaptive coding and modulation.

IV. RESULTS

In order to demonstrate the capabilities of the simulation tools, some RRM schemes have been analyzed and reported here as examples.

The effect of power control and adaptive coding and modulation on the system performance is presented in Figs. 4-7. We have analyzed the system performance without power control or adaptive coding and modulation as a reference case. This reference case has been repeated at two different coding rate (1/2 and 3/4) and 16-QAM. The two coding-modulation combinations (1/2-16QAM and 3/4-16QAM) correspond to throughput values of 2 and 3 b/s/Hz respectively.

Power Control is implemented using the Distributed Constrained Power Control (DCPC) [9] at the same two throughput values mentioned above. Adaptive coding and modulation (without power control) also has been tested. 11 coding-modulation levels have been employed as shown in Table I. Also, a joint algorithm for power control and adaptive coding and modulation has been analyzed. This algorithm uses the same 11 coding-modulation levels listed in Table I combined with power control. In addition, this algorithm makes use of BSs cooperation to assist users having poor channel conditions by lowering the transmission rate of cochannel users and in turn their transmission power. Users who fail to achieve the minimum target SIR are switched off (temporarily) with a probability that is linearly proportional to the difference between the achieved SIR and target SIR (SIR^t). More details about this algorithm can be found in [10].

Fig. 4 shows the total throughput of the different power and rate control schemes mentioned above. Without Adaptive Coding and Modulation (ACM), the total throughput is constant. It is worth noting that the PC results and no PC results are overlapped. With adaptive coding and modulation (with and without PC), the total throughput decreases (almost) linearly with system loading increasing. With PC, ACM can achieve higher throughput at light loading, while at medium and heavy loading value, ACM without PC can achieve higher throughput. This is due to the fact that the joint scheme turns some users off when they can not achieve the minimum SIR (SIR^t).

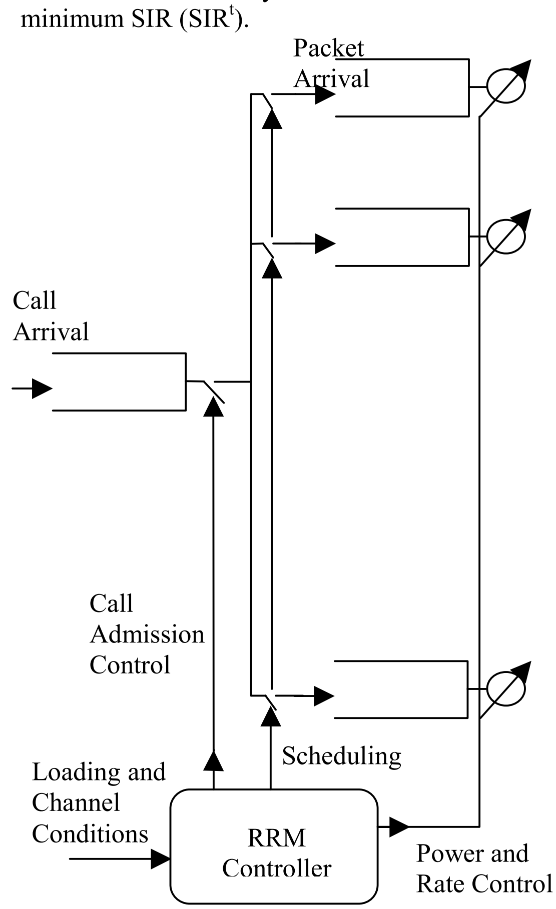

Fig. 3. Radio Resource Management (RRM) Model.

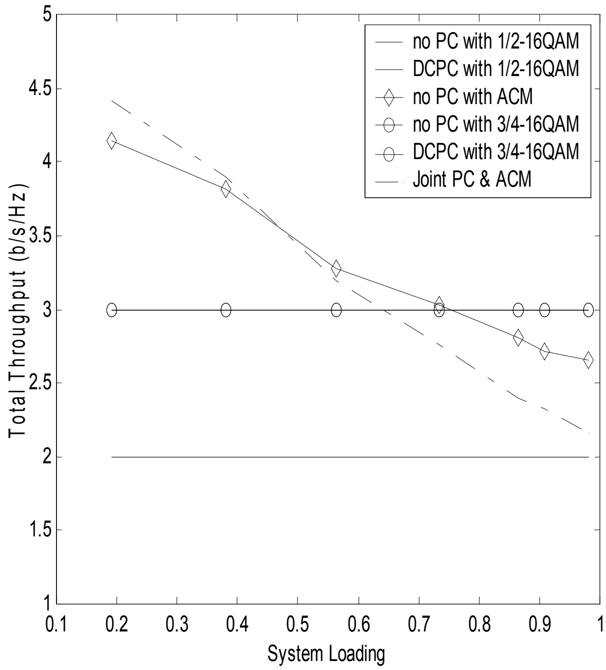

Fig. 4. Total throughput dependence on system loading.

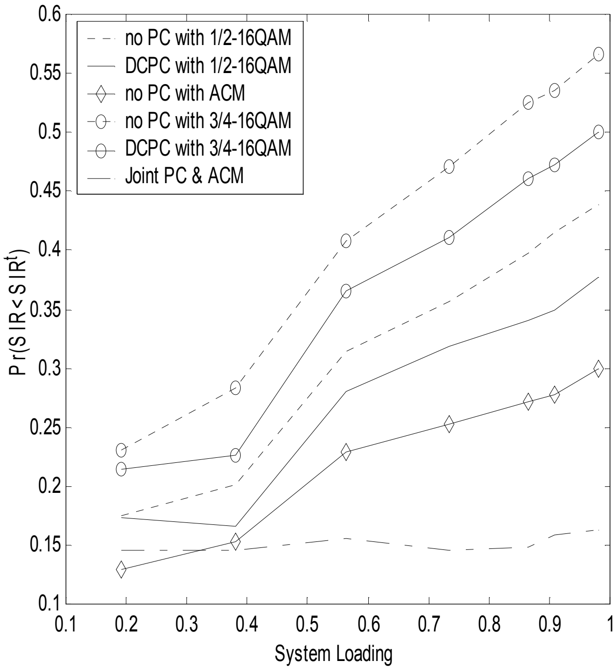

Fig. 6. Probability of SIR less than target SIR(SIR^t).

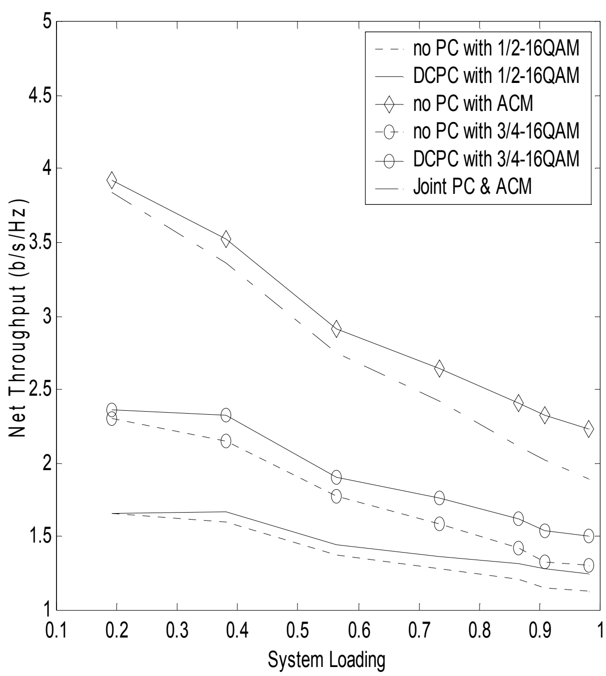

Fig. 5. Net throughput dependence on system loading.

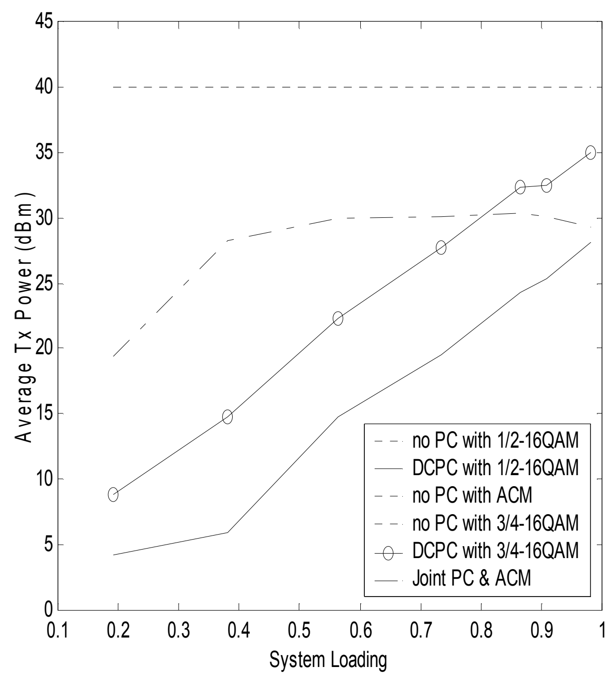

Fig. 7. Average transmission power per user.

TABLE I
SIR OF DIFFERENT CODING- MODULATION LEVELS

Coding-modulation level (*k*)	Coding rate & Modulation level combinations	Spectral Efficiency (b/s/Hz)	Target *SIR* at 10^{-6} BER (SIR^t) dB
1	½ & QPSK	1.00	4.65
2	2/3 & QPSK	1.33	6.49
3	¾ & QPSK	1.50	7.45
4	7/8 & QPSK	1.75	9.05
5	1/2 & 16-QAM	2.00	10.93
6	2/3 & 16-QAM	2.66	12.71
7	3/4 & 16-QAM	3.00	14.02
8	7/8 & 16-QAM	3.50	15.74
9	2/3 & 64-QAM	4.00	18.50
10	3/4 & 64-QAM	4.50	19.88
11	7/8 & 64-QAM	5.25	21.94

The net throughput, which is defined as the total throughput after excluding the erroneous frames, is depicted in Fig. 5. It is evident that ACM (without power control) achieves the highest net throughput at all loading values. With fixed coding and modulation, PC enhances the net throughput particularly at heavy loading.

Fig. 6 shows the probability that the SIR is less than the target SIR (SIR^t). The joint PC & ACM keeps this probability almost fixed around 0.15 which is the lowest value at loading values greater than 0.32. AMC achieves the lowest Pr ($SIR<SIR^t$) at loading values less than 0.32 but fails to keep this superiority at medium and high loading. It is also worth noting that PC can reduces Pr ($SIR<SIR^t$) at all loading values.

Finally, the average transmission power (in dBm) is plotted in Fig. 7. It is worth noting that the ACM results and no PC results with and without PC are overlapped. It is apparent PC reduces the average transmission power significantly specially at light loading and with low coding and modulation levels.

V. SUMMARY AND CONCLUSIONS

We have presented the structure and model of a simulation testbed for RRM schemes and QoS performance analysis. Also, some results of different power and rate control are given as examples to demonstrate the simulation tool capabilities. From these results, it has been shown that adaptive coding and modulation can achieve higher throughput than other schemes. However, combining adaptive and modulation with power control can achieve a better signal quality at the expense of a slight reduction of the average throughput.

ACKNOWLEDGMENT

The authors would like to thank Dr. Sirikiat Lek Ariyavisitakul for providing us with the *SIR* values of different coding-modulation levels.

REFERENCES

[1] J. Zander, and S. Kim, *Radio Resource Management for Wireless Networks*, Artech House, Norwood, U.S.A. 2001.

[2] N. Shankaranarayanan and A. Srivastava, "On the design of broadband fixed wireless packet networks," *Proc. of IEEE Globecom*, pp. 1930-1934, 1998.

[3] C. Baugh and J. Huang, "Traffic model for 802.16 TG3 MAC/PHY Simulations," *IEEE 802.16.3c-01/53*, March 2001.

[4] V. Erceg et al., "An empirically based path loss model for wireless channels in suburban environments," IEEE JSAC, vol. 17, no. 7, pp. 1205-1211, July 1999.

[5] V. Erceg et al., "Channel models for fixed wireless applications," *IEEE 802.16.3c-01/29r1*, February 2001.

[6] A. Toledo, A. Turkamni, and D. Parsons, "Estimating coverage of radio transmission into and within buildings at 900, 1800, and 2300 MHz," *IEEE Personal Communications*, pp. 40-47, April 1998.

[7] A. Meier and T. Kurner, "Propagation Models for the prediction of indoor coverage by outdoor base stations at 1.8 GHz," *EPMCC 2001*, February 2001.

[8] D. Baum, "Simulating the SUI channel models," *IEEE 802.16.3c-01/53*, April 2001.

[9] S. Grandhi, J. Zander, and R. Yates, "Constrained power control," *Wireless Personal Communications*, vol. 1, pp. 257-270, 1995.

[10] M. Ahmed, H. Yanikomeroglu, D. Falconer, and S. Mahmoud, "A joint adaptive transmission rate selection and power control algorithm for broadband TDMA/TDM wireless access networks," Submitted to *IEEE Globecom02*, Taiwan, 2002.