Capacity Dimensioning for Wireless Communications System

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1. Introduction

With the development of mobile communications system, lots of novel techniques in wireless link had been invented by research institutes and adopted by different kinds of mobile communications system standards[1-2]. Meanwhile, there are still many new technologies emerging for standardization of next generation mobile communications system [3].

Capacity dimensioning methods have been continuously exploited for the system capacity performance evaluation and wireless network planning in development process of any generation of mobile communications system. All of the capacity dimensioning approaches can be divided into two main groups, i.e. the analytical methods and the simulation methods. Analytical methods give the close-form expression of system capacity with system parameters, transmission techniques and wireless network architecture, user distribution and wireless services by establishing mathematical models and get the capacity solutions by computer calculations. The simulation methods simulate the system process by precisely establishing simulation platform and analyze the system capacity through Monte Carlo simulation procedure. Performance comparisons of the two kinds of methods are shown in table X.1.1.

	simulation method	analytical method
Precision	Precise under any condition	Accuracy of the result depends on the mathematical methods
Time cost	Much time	Less time
Complexity	Cost a lot of computations. Powerful computer is necessary	Cost less computations
Convenience	It is not easy to establish simulation platform	If using accurate mathematical models, it will be convenient to solve practical problems

Table X.1.1 Comparisons of simulation method and analytical method

2 Analytical Methods of Capacity Dimensioning

Analytical capacity dimensioning methods include approaches of limited system resources-based capacity dimensioning, system interference model-based capacity dimensioning and queue-based capacity dimensioning.

2.1 Limited System Resources-Based Analytical Approaches

Ignoring the factors of self-interference and supposing all of the radio resources be orthogonal, limited system resources-based analytical method considers radio resources like spectrum bandwidth in FDMA system, time slots in TDMA system, code channels in CDMA system, subcarriers in OFDMA system, antennas in MIMO system or mixture of the radio resources in multi-dimensions radio resource mobile communications system. By taking the total number of radio resources occupied by system as system states and constructing Markov chain, the system capacity can be calculated based on the stationary state distribution of Markov chain. If system resources are modeled properly, this approach is applicable for any kind of mobile communications system. But, it is not accurate for CDMA system due to its self-interference.

[4] extended the Erlang B/C law to multi-service as multi-service Erlang B law and hybrid multi-service Erlang B/C law for the performance evaluation of UMTS with multi-services. By using Markov chain-based system resources modeling method for estimation of Erlang capacity of CS domain voice service and recursive algorithm proposed by Kauffman and Roberts for calculating the stationary state distribution of the Markov chain, it obtained a closed-form expression to calculate the blocking rate for each service in a multi-service context. And also, it got a UMTS radio dimensioning flow chart for offering more accurate dimensioning.

[5] presented a multi-service dimensioning procedure for evaluation of the number of CDMA cells needed in a given area based on the analysis of an original CDMA multi-service uplink capacity estimation model and the multi-service Erlang-B formula.

[6] made a contribution to the generic problem of having simple and accurate models to estimate radio cells with data traffic on a GPRS or EDGE network for avoiding the derivation of any multi-dimensional Markovian (or semi-Markovian) model. On the basis of ON/OFF modeled service, the number of time slots occupied by system could be modeled as first-order Markov chain. Capacity of GPRS/EDGE was figured out by calculating stationary state distribution of the Markov chain.

2.2 System Interference Model-Based Analytical Approaches

System interference model-based analytical method calculates the system capacity based on uplink/downlink interference model in the system and Shannon information capacity theorem. Markov chain can be used to model the number of users in the system. This method is applicable for any kind of mobile communications system with consideration of system interference and especially for CDMA system as the number of users in CDMA system is restricted by the interference of uplink and the transmit power of downlink.

[7] evaluated the cell capacity of the HS-DSCH channel in HSDPA in the presence of circuit switched (CS) services based on description of the SIR expression of an HSDPA user in the presence of CS users and power consumption and code tree resources consumption of CS services. Hybrid Automatic Repeat Request (HARQ), Fast Cell Selection, Adaptive

Modulation and Coding (AMC) were revisited for the capacity calculation of the HS-DSCH channel. Monte Carlo simulation was performed for the verification of the correction of the analytical expressions.

[8] analytically estimated the cell throughput of HSDPA based on the analysis of distribution of SNR and influence of AMC, HARQ and different scheduling algorithms, analyzed the TCP model and effect of TCP on wireless network on condition of different scheduling algorithm.

[9] presented an analytical model for the evaluation of UMTS HSDPA capacity based on the analytical estimation of SINR for quality of service guarantee, used the model for the capacity performance comparison of different MIMO transmission scheme (space time coding and BLAST) and proposed the use of adaptive MIMO in the HSDPA system with the aim of increasing cell capacity.

[10] estimated the MIMO/HSDPA cell capacity for UMTS by a proposed semi analytical model and analytical framework. The model included the effect of fast fading, mobility and coverage by establishing interference model with fast fading, mobility model and coverage model. The performances of MIMO with different transmission scheme were also investigated.

[11] compared the cell capacity of HSDPA with adaptive modulation and coding, Hybrid ARQ, fast scheduling, fast cell selection and different MIMO transmission schemes (space time coding and Blast) by introducing an analytical method based on the interference model establishment.

[12] compared the cell capacity of a proposed scheduling algorithm to the cell capacity of other scheduling algorithms in HSDPA by introducing an analytical interference model with the assumption of a dense multipath frequency selective channel with uncorrelated signal envelope following a Rayleigh distribution and Wide-sense Stationary Uncorrelated Scattering (WSSUS) radio channel.

[13] evaluated the reverse link capacity of a CDMA cellular voice system by analysis of system interference and blocking probability.

[14] defined downlink multiservice loading as performance parameter of system capacity, set up a comprehensive downlink dimensioning framework for capacity and coverage analysis of downlink in WCDMA system, analyzed the influence of offered bandwidth, non-orthogonal factor, soft handover and diversity gain, output power, shadowing to system capacity.

[15][16][17] derived the close-form expression of outage probability and the forward-link Erlang capacity for CDMA system forward link with mixed multi-rate sources based on the establishment of data traffic model, system interference model, introduction of the forward-link power factor and impact of soft handoff.

[18] designed a recursive procedure for calculation of system throughput and blocking probability in the presence of power control error in CDMA system based on the establishment of a three-dimensional Markov chain for the integrated CS/PS system model, intercell and intracell interference model in different conditions of perfect power control and imperfect power control.

[19] extended the notion of capacity for the consideration of wireless service quality of service requirements influence, evaluated the uplink capacity for single cell scenario and multi-cell scenario of a multi-service WCDMA system based on the analysis of system interference model, real time service model and best effort model.

[20] presented a capacity dimensioning flow chart of for WCDMA with HSDPA and HSUPA based on the analysis of link level capacity and system level capacity. Supposing that HSDPA system work in a TDM mode and each user has sufficient services to transmit, only one user be scheduled during each time slot in system level capacity analysis, interference model was established directly according to the interference model, PDF of user's receiving SNR used in capacity dimensioning was derived by using different scheduling algorithms. Then, the system performances including the sector throughput and user satisfied percentage of WCDMA with HSDPA and capacity with HSUPA were calculated.

2.3 Queue-Based Analytical Approaches

Queue-based analytical method combines Markov chain modeling of the wireless transmission channel states in air interface and Markov chain modeling of the wireless service transmission buffer states into a multi-dimensional Markov chain. The system capacity can be calculated by solving the stationary state distribution of the multi-dimensional Markov chain. Theoretically, this method is qualified to any system if the mathematical model of Markov chain can be properly constructed for the mobile communications system and wireless service transmission buffers.

[21] extended RIO (random early drop routers with in/out bit) algorithm to 5 class wireless services by continuous-time 2-D Markov chain including wireless link state and wireless services states, derived the state transition probability for the calculation of the stationary state distribution of Markov chain by matrix analysis, obtained system performance like system throughput and queuing delay time.

[22] compared the system performance like relative system throughput and average queued packets number of a proposed dynamic rate allocation technique with traditional static rate allocation technique in HSDPA system by derivation of a discrete time Markov model of the system and establishment of three kinds of traffic models, verified the analytical method by simulation process.

[23] [24] established system model for wireless system with adaptive modulation and coding (AMC), analyzed system performance by Markov chain diagram describing the transition of the pair containing both service queues and channel states, and given a cross layer design example.

[25] developed two discrete time Markov chain for the quality of service (QoS) evaluation of TCP-Friendly Rate Control protocol (TFRC) in hybrid wireless/wired networks, one is for analysis of link utilization and packet loss rate, and the other is for delay performance analysis.

[26] proposed a four-dimensional discrete time Markov chain (DTMC) model to describe the system behavior of HSDPA system with different PS wireless services, investigated the effect of AMC, HARQ and the packet multimedia traffics by a discrete Markov modulated Poisson process (D-MMPP), derived closed-form expressions for the system performance metrics such as throughput, delay and packet loss rate based on the stationary state distribution of the DTMC, provided analytical and simulation results for the validation of the analytical method.

3 Simulation Methods of Capacity Dimensioning

Simulation methods of capacity dimensioning can provide more accurate results and involve the approaches of event driven-based simulation platform and time driven-based simulation platform. Both of the simulation methods can be applied to any wireless communications system with time consuming work.

3.1 Event Driven-Based Approaches

Event driven-based simulation method describes the system's behavior by state machine mechanism in simulation environment like OPNET or C/C++. The communications procedures in the wireless communications system are simulated by the event drive transitions among the established states. The average throughput, packet loss rate, custom satisfaction and service transmission delay can be calculated in the simulation process.

[27] carried out extensive system level simulation for WCDMA system with various real time wireless service and mixed wireless services of real time service and non-real time service by event-based simulation implemented in OPNET platform, studied the single service capacity, average session throughput of mixed wireless services, custom satisfaction and session outage.

3.2 Time Driven-Based Approaches

Time driven-based simulation method simulates system behavior based on time-shift. According to the continuous of different simulation scenarios, time driven-based simulation methods can be divided into three groups, i.e. static, dynamic and hybrid simulation-based capacity dimensioning.

In static simulation method, system behavior is modeled as discrete actions by a series of irrelevant snapshot procedures.

[28] described statistic relations among the system and environment parameters (propagation, terminal distribution within the cells, base station distribution) by the linear equations for wireless network modeling, got the characteristics results of transmitting/receiving power and system capacity (number of users in a cell) for UMTS WCDMA system by simulation method.

In dynamic simulation method, the communications scenarios are relative with each other. System parameters are treated as the functions of time which can be used to describe the communications behavior.

[29] described a detailed simulation methodology consideration to HSDPA system based on the analysis of key techniques in HSDPA, gave the simulation results of transmitted cell power distribution, cell throughput, per HSDPA-user throughput by dynamic simulation in a standard three sector network topology, and discussed environment sensitivity of simulation platform.

[30] compared the achievable throughput performance of three different scheduling algorithms, analyzed the influence of the number of access users and traffic on throughput by establishing a dynamic simulation platform for HSDPA system.

[31] presented physical layer performance and system performance of HSDPA by dynamic simulation method.

[32] established a comprehensive simulation tools for evaluation of URTRA FDD system with mixed services of circuit switching domain and packet domain by using pipeline mechanism for modeling of wireless channel to dynamic simulation procedure.

Hybrid simulation method is a mixture of static and dynamic simulation method. This method usually uses static simulation method as main simulation process and embeds dynamic simulation method into part of simulation platform. It can get more detail simulation results than static simulation method and save time than dynamic simulation method.

[33] presented a novel simulation method by using short-term dynamic (STD) simulation concept, divided simulation process into two stages i.e. snapshot stage for static simulation of system and establishment of HSDPA components for dynamic simulation in order to make a fast UMTS HSDPA planning simulation.

[34] evaluated various performance indicators (capacity, coverage, call blocking and dropout probabilities, packets delay and performance of burst admission) of forward link in CDMA cellular systems with mixed services of voice and high speed packet-switched service by using static simulation for static system capacity and cell coverage and dynamic simulations for the influence of shadow fading in an urban environment, mobility and soft handoff events.

4 Conclusions and Discussions

Capacity dimensioning methods can be divided into analytical approaches and simulation approaches for wireless network in mobile communications system. Previous contributions showed that analytical methods establish mobile communications system model by using mathematical expressions of limited radio resources, system interference and transmission queues for fast capacity dimensioning and simulation methods set up simulation platform by using static, dynamic and hybrid ways to simulate the action of mobile communications system for accurate capacity dimensioning. Both methods can be used for correctness verification of each other.

With the development of mobile communications system and the appearance of novel technologies in physical layer (like MIMO, OFDM and etc.), wireless network architecture (such as flat wireless network, mesh wireless network, relay wireless network, cooperative wireless network) and wireless services, capacity dimensioning is still an open issue for further investigations.

5. Reference

[1] Subramanya, S.R.; Yi, B.K., 'Mobile communications - an overview', Potentials, IEEE Volume 24, Issue 5, Dec. 2005 Page(s): 36–40.

[2] Erik Dahlman, Stefan Parkvall, Johan Skold and Per Beming, 3G Evolution: HSPA and LTE for Mobile Broadband, Academic Press, October 3, 2008.

[3] http://www.itu.int/ITU-R

[4] Adiego D, Cordier C. 'Multi-service radio dimensioning for UMTS circuit-switched services', IEEE 54th VTC, 2001, pp. 2745–2749.

[5] Brandin H. 'A multiservice dimensioning procedure for 3G CDMA', 3G Mobile Communication Technologies, 2000. First International Conference on, 27-29 March 2000 Page(s): 406-410

[6] Georges N, Bruno B, Pierre E., 'An analytical model for the dimensioning of a GPRS/EDGE network with a capacity constraint on a group of cells', International Conference on Mobile Computing and Networking, 2005.

[7] Assaad M, Zeghlache D., 'Effect of circuit switched services on the capacity of HSDPA', IEEE Transactions on Wireless Communications, 2006, 5: 1044-1054.

[8] Assaad M, Zeghlache D., 'Cross-Layer design in HSDPA system to reduce the TCP effect', IEEE Journal on Selected Areas in Communications, 2006, 24: 614-625.

[9] Assaad M, Zeghlache D., 'Comparison between MIMO techniques in UMTS-HSDPA system', IEEE Eighth International Symposium on Spread Spectrum Techniques and Applications, 2004, pp 874-878, Sep 2004.

[10] Assaad M, Zeghlache D. 'MIMO/HSDPA with fast fading and mobility: capacity and coverage study', 15th IEEE International Symposium on Personal Indoor and Mobile Radio Communications, 2004, 3: 2181–2186.

[11] Assaad M, Zeghlache D., 'On the capacity of HSDPA' IEEE GlOBECOM, 2003, 1: 60-64.

[12] Assaad M, Zeghlache D., 'Scheduling study in HSDPA system', IEEE 16th International Symposium on Personal, Indoor and Mobile Radio Communications, 2005, 3:1890-1894.

[13] Viterbi A M, Viterbi A J., 'Erlang Capacity of a Power Controlled CDMA System', IEEE Journal on Selected Areas in Communications, 1993, 11(6): 892-900.

[14] Cordier C, Ortega S., 'On WCDMA downlink multiservice coverage and capacity', IEEE 54th Vehicular Technology Conference, 2001, 4:2754 - 2758.

[15] Wan Choi, Jin Young Kim, 'Forward-link capacity of a DS/CDMA system with mixed multirate sources', IEEE Transactions on Vehicular Technology, 2001, 50(3): 737–749.

[16] Wan Choi, Jin Young Kim, 'Forward link capacity of 3G wideband CDMA system with mixed traffic sources', Vehicular Technology Conference IEEE 53rd VTC, 2001, 4:2620–2624.

[17] Wan Choi, Byung Shik Kang, Jun Cheol Lee, et al. 'Forward link Erlang capacity of 3G CDMA system', 3G International Conference on Mobile Communication Technologies, 2000, pp. 213–217.

[18] Lin Wang, Aghvami A H, Chambers W, et al. 'Performance Analysis of an Integrated CS/PS Services CDMA System', IEEE Transactions on Vehicular Technology, 2005, 54:1488–1499.

[19] Nidhi Hegde, Eitan Altman, 'Capacity of Multiservice WCDMA Networks with Variable GoS', Wireless Networks, 2006, 12(2): 241-253.

[20] Zhao X, Qi J, Liang H, 'An Analytical Method for Capacity Dimensioning of WCDMA with High Speed Wireless Link', Proc. IEEE Wireless Communications and Network Conference, pp. 4172-4176, Mar. 2007.

[21] Gyasi-Agyei A., 'Performance analysis of differentiated services over wireless links', 5th IEEE International Conference on High Speed Networks and Multimedia Communications, 2002, pp. 86–90.

[22] Caponi L, Chiti F, Fantacci, 'A dynamic rate allocation technique for wireless communication systems', IEEE International Conference on Communications, 2004, 7:4263–4267.

[23] Qingwen Liu, Shengli Zhou, Georgios B Giannakis, 'Queuing with adaptive modulation and coding over wireless links: Cross-layer analysis and design', IEEE transactions on wireless communications, 2005, 4:1142-1153.

[24] Xin Wang, Qingwen Liu, Georgios B Giannakis, 'Analyzing and Optimizing Adaptive Modulation Coding Jointly With ARQ for QoS-Guaranteed Traffic', IEEE Transactions on Vehicular Technology, 2007, 56: 710-720.

[25] Shen H, Cai L, Shen X., 'Performance analysis of TFRC over wireless link with truncated link-level ARQ', IEEE Transactions on Wireless Communications, 2006, 5: 1479-1487.

[26] Xinsheng Zhao; Hao Liang; Zhenjie Gu; "A Markov Chain-Based Capacity Dimensioning Method for Wireless Communications System with AMC, HARQ and Packet Multimedia Traffic Source" Communications, 2008. ICC' 08. IEEE International Conference on 19-23 May 2008 Page(s):429–434

[27] Malik S A, Zeghlache D., 'Downlink capacity and performance issues in mixed services UMTS WCDMA networks', IEEE 55th Vehicular Technology Conference, 2002, 4:1824-1828.

[28] Bem D J, Nawrocki M J, Wieckowski T W, et al. 'Modeling methods for WCDMA network planning', IEEE 53rd Vehicular Technology Conference, 2001, 2: 962–966.

[29] Pedersen K I, Lootsma T F, Stottrup M, et al. 'Network performance of mixed traffic on high speed downlink packet access and dedicated channels in WCDMA', IEEE 60th Vehicular Technology Conference, 2004, 6: 4496–4500.

[30] Ofuji Y, Morimoto A, Abeta S, et al., 'Comparison of packet scheduling algorithms focusing on user throughput in high speed downlink packet access', IEEE 13th International Symposium on Personal, Indoor and Mobile Radio Communications, 2002, 3:1462–1466.

[31] Love R, Ghosh A, Weimin Xiao, et al., 'Performance of 3GPP high speed downlink packet access (HSDPA)', IEEE 60th Vehicular Technology Conference, 2004, 5: 3359–3363.

[32] Adiego and Cordier C., 'Multi-service Radio Dimensioning for UMTS Packet-Switched Services', IEEE Proceeding of PIMRC, 2002, 5: 2409–2413.

[33] Turke U, Koonert M, Schelb R, et al., 'HSDPA performance analysis in UMTS radio network planning simulations', IEEE 59th Vehicular Technology Conference, 2004, 5:2555–2559.

[34] Abarca-Reyna J P, Lara-Rodriguez D., 'Performance evaluation of the downlink CDMA cellular system supporting integrated voice/data traffic', IEEE 61st Vehicular Technology Conference, 2005, 5:2741–2745.

Mobile and Wireless Communications Physical Layer Development and Implementatiom

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Mobile and Wireless Communications have been one of the major revolutions of the late twentieth century. We are witnessing a very fast growth in these technologies where mobile and wireless communications have become so ubiquitous in our society and indispensable for our daily lives. The relentless demand for higher data rates with better quality of services to comply with state-of-the art applications has revolutionized the wireless communication field and led to the emergence of new technologies such as Bluetooth, WiFi, Wimax, Ultra wideband, OFDMA. Moreover, the market tendency confirms that this revolution is not ready to stop in the foreseen future. Mobile and wireless communications applications cover diverse areas including entertainment, industrialist, biomedical, medicine, safety and security, and others, which definitely are improving our daily life. Wireless communication network is a multidisciplinary field addressing different aspects raging from theoretical analysis, system architecture design, and hardware and software implementations. While different new applications are requiring higher data rates and better quality of service and prolonging the mobile battery life, new development and advanced research studies and systems and circuits designs are necessary to keep pace with the market requirements. This book covers the most advanced research and development topics in mobile and wireless communication networks. It is divided into two parts with a total of thirty-four stand-alone chapters covering various areas of wireless communications of special topics including: physical layer and network layer, access methods and scheduling, techniques and technologies, antenna and amplifier design, integrated circuit design, applications and systems. These chapters present advanced novel and cutting-edge results and development related to wireless communication offering the readers the opportunity to enrich their knowledge in specific topics as well as to explore the whole field of rapidly emerging mobile and wireless networks. We hope that this book will be useful for students, researchers and practitioners in their research studies.

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