Towards a Novel Resource Management Scheme in Wireless Networks Based on Quality of Experience (QoE)

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Abstract— **This paper summarizes some of the initial research findings obtained in the SERMON project, funded by Wireless@KTH. The main focus of this paper is on video streaming transmission and the quantification of how much can be gained, in terms of user satisfaction and network resource utilization, by exploiting this semantic knowledge at network level. For this purpose, different QoE-centric RRM strategies are proposed and their performances evaluated in respect to a "classical" agnostic scheme, in a scenario where users have different QoE requirements for different content types and as a function of the device screen resolution during a live video streaming transmission..**

I. INTRODUCTION

Predictions for future needs for wireless communication vary widely from 1 to 3 orders of magnitude increase in the next 10 years. However, most predictions seem to agree with an almost exponential increase in the growth of mobile services and applications (apps), for the same period. More base stations, data caps or limiting the access to some mobile services are not the only answer to this challenge. There is a clear need for novel and disruptive end to end considerations of the wireless eco system, which will enable and sustain the next generation of mobile services and user experience. In particular, wireless networks are currently agnostic and non convergent. Although QoE depends in large measure on the end to end QoS, the knowledge separation between the service designer/builder, service provider, delivery network, terminals OS and wireless networks, are producing substantial resource optimization deficiencies and discontinuities (spectrum and energy included). Further, the wireless networks have no knowledge on the type and characteristics of the specific mobile services they are providing (they are agnostic). Moreover, mobile service models are getting more apps oriented and that in itself represents a relevant expansion of the mobile service model. There is also an expectation for the proliferation of continuous mobile services and connected devices with very specific models of real time wireless connectivity requirements. Thus, an effective way to optimize the utilization and sustainability of future mobile services and networks might consists of including semantic knowledge, describing the models of resource utilization related to a desired QoE for a class of mobile services/apps, in the resource management schemes of cellular systems.

With the previous considerations, the project described in this paper develops a first approach to the role of QoE evaluation in mobile networks scenario and its impact over the resource allocation. In the initial part, this problem is analyzed in a basic scenario in order to understand how the QoE might be introduced in a resource management scheme so that users and operators may be benefited in a long term. In this paper, novel approaches for resource allocation based on the evaluation of the QoE (Proportional fair based on QoE and user with the lowest QoE so far) are proposed and compared with the Carrier to Interference (C/I) criteria. Later, the impact over the general QoE average in the network is measured.

The rest of the paper is organized as follows. The problem statement with a brief description of the motivation of this paper is discussed in section II. The system model and its explanations are addressed in section III. The mechanism implemented in this project is shown in section IV. Section V presents the simulation model and the experimental results. Conclusions and future work are drawn in the last section.

II. PROBLEM STATEMENT

The transition from traditional voice services to data services with heterogeneous requirements necessitates a review of the radio resource management schemes. Resource management must consider the impact of error prone transmission medium, heterogeneity of application requirements, and issues related to fairness among users. Also, there is a need to differentiate users based on the amount of revenue they are willing to pay and their expectations from the services. In that sense, the identification of the effect of QoE parameters on the radio resource management and the consequences of that in user´s satisfaction is an important research challenge.

The majority of the research in the resource allocation field considers the resource allocation from the QoS perspective where improving spectral efficiency, service latency, delay variation (jitter), etc., is the way to provide a good service to the users. However, minor attention has been paid to the satisfaction of the subjective quality requirements from human users. With the project COSEM [8], research about the relationship between QoS and QoE is starting. The idea is use network context and user context information to improve the user experience.

This motivates to develop the first approach of QoE evaluation in mobile networks scenario and its impact over the resource allocation in a wireless network as element to decide which user will receive the resources during a wireless communication. To do this, it is considered a video streaming service in which it seeks to develop a QoE-aware scheme for it. Video transmission is one of the most used applications over the network around the world. With this, the effect of the QoE of users with this service will be important in the value chain of telcos. Now, the point is to determine the way in that QoE and semantic knowledge will be incorporated as key factors in the radio resource allocation. At the same time, it will be necessary to evaluate the impact of this new model in the user's perception regarding a specific kind of service and the improvement achieved with the incorporation of this criterion.

III. SYSTEM MODEL

This project has a basic scenario consisting of a single Base Station (BS) and N-users interested in receiving each a "live" video stream. The users are classified in function of two types of video content: high or low movement videos. The former type requires much higher rates than the latter, in order for the user perception to be associated to high Mean Opinion Score (MOS) values. Model focused on the downlink transmission slots. These slots (with a duration of 2ms according to the HSDPA standard), are allocated to different users. Channels assigned have two possible states: bad (with data rate from 50 to 150 kbps) or good (with data rate from 500 kbps to 2Mbps). Each state has different probabilities as is shown in Figure 1.

In this scenario the MOS performances are evaluated for three different resource allocation schedulers: one based on C/I (Scheme 1), one adopting a proportional fair QoE-aware method (Scheme 2), and one serving the users currently with lowest instantaneous QoE (Scheme 3). The mapping between the instantaneous data rate and the perceived QoE (Vq, Video Quality Metric used as estimation for the MOS values) is computed considering the parametric model for perceptual video quality estimation proposed in [13] and expressed in (1). This model also includes various display formats (SD, VGA, CIF, QCIF) and different Codec Factors (MPEG-2 or H.264).

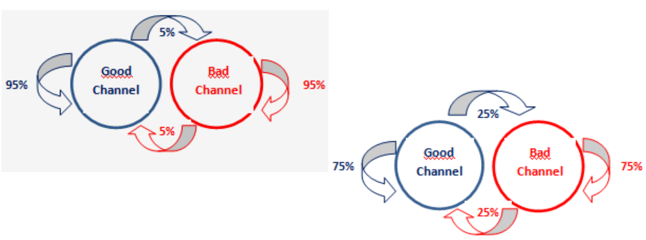

Fig 1. Channel states

$$Vq = 1 + 4k\left(1 - \frac{1}{1 + \left(\frac{ab}{v_4}\right)^{v_5}}\right) \quad (1)$$

Where **Vq** corresponds to the Video Quality Metric used as estimation for the MOS values. MOS values goes from 1 for bad quality to 5 for high quality evaluation. In this formula, **b** is the bit rate expressed in Mb/s; **a** is a value related to the display format (SD, VGA, CIF, QCIF); and **k** expresses the Codec Enhancement Factor (MPEG-2 or H.264). Parameters used in the model are defined in [13]. These values are presented in tables I, II and III

TABLE I
K1 AND K2 PARAMETERS VALUES

k =1 forMPEG-2.
$k = 1 + k1.e^{-k2.a.b}$ for H.264.
k1= 1.36, k2= 1.93

TABLE II
V4 AND V5 PARAMETERS VALUES

Movement	Optimal v4	Optimal v5
Low Movement	0.366	1.32
High Movement	1.088	1.56

TABLE III
BEST VALUES FOR a

Display format	Value for a
SD	1
VGA	1.4
CIF	3.2
QCIF	10.8

For the test using factors for H.264 video codec and as display formats values for SD and QCIF were considered, in order to compare different resolution values as shown in table III.

According to the model, all the clips have better perceived quality for higher bit rates, as can be expected. However, at low bit rates there are high differences in the perceived quality for identical coding conditions, depending on video content. This is shown in Figure 2.

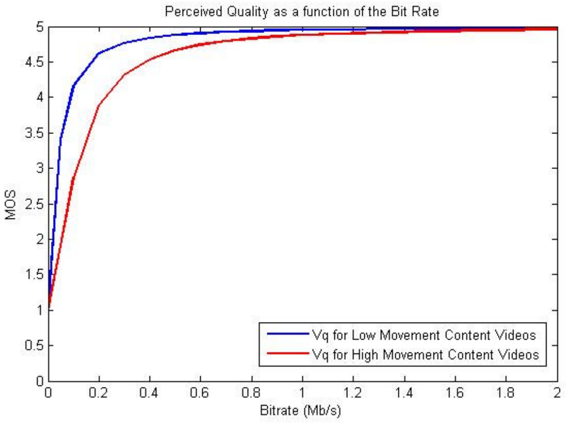

Fig 2. Perceived Quality as a function of the Bit Rate.

IV. QoE Aware Radio Resource Management

Three resource allocation schemes were considered during the project. In all cases QoE evaluation model was considered. In the first case (Scheme 1), as a parameter to evaluate the service quality offered after the slot allocation. In second and third cases (Scheme 2 and 3), QoE evaluation model was used as a factor to allocate the resources. However the criteria to use QoE factor is different in each case. The following describes in detail each scheme.

A. C/I Scheme (RRM1)

In this scheme, user with the highest data rate (highest signal quality) will receive the slot of time to transmit during the time slot n. After the resource allocation, the QoE of all users is evaluated, measuring the QoE average by kind of user (for each individual user). Figure 3 describes this scheme.

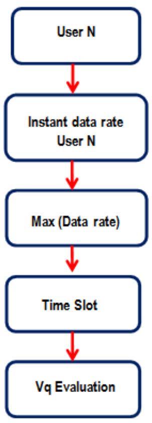

Fig 3. C/I scheme description

B. Proportional fair based on QoE

Using this scheme, the first step includes the evaluation of the QoE in the next time slot (t+1), considering the allocation and the no allocation of the user in time (t+1). After this, the difference between the QoE values in different situations is calculated. Time slot is assigned to the user with the maximum delta value, in order to maintain the average QoE in the network. In this scenario, the resource allocation is done based on the evaluation of the QoE for both classes of users. Figure 4 describes this scheme.

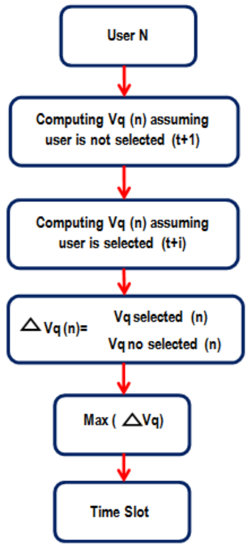

Fig 4. Resource allocation based on Proportional fair QoE

C. Serving the user with the lowest QoE so far

Last scheme considered the evaluation of the QoE for each user during the previous period of time. The objective of this mechanism is finding the user with the lowest QoE; assign the slot to this user in order to improve the average QoE in the network. Figure 5 describes this scheme.

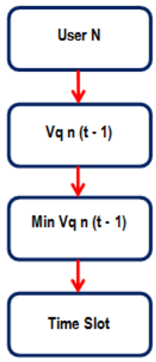

Fig 5. Resource allocation based on lowest QoE criterion

V. Simulation Model

To validate the proposed model, we conducted extensive simulation experiments. We evaluate the performance of the proposed schemes. For simplicity, the simulation considers only a single cell. It was assumed that all N users can be classified considering two types of videos: High movement and slow movement videos. Simulation ran considering a snapshot of the system during 5 minutes. The simulations were run for different numbers of users in the cell, between 4 and 20, with 0.75 and 0.95 probability of get access to a good channel conditions.

A. *Performance Measures*

To assess the performance achievable with the proposed schemes, the performance measure selected for analyzing the behavior of the proposed schemes is the average delta QoE (ΔQoE). ΔQoE evaluates the percentage of improvement or deterioration in the QoE establishing a relation between the new resource allocation scheme and the classical resource allocation scheme and is computed as

$$\Delta QoE = \frac{\overline{Vq}_x}{\overline{Vq}_1} \quad (2)$$

Where $\overline{Vq}_x$ represents the average Video Quality Metric for the scheme 2 or 3 (Proportional fair based on QoE or Serving the user with the lowest QoE so far) and $\overline{Vq}_1$ represents the average Video Quality Metric for the C/I scheme. This average corresponds to the evaluation of QoE using (1) for both low movement videos and high movement videos, with different number of users connected to the BS and different channel conditions.

VI. RESULTS

Figure 6, 7 and 8 show the different results of the QoE evaluated with different number of users and conditions of channel, display and percentages of users receiving High and low movement videos (30/70; 50/50; 70/30).

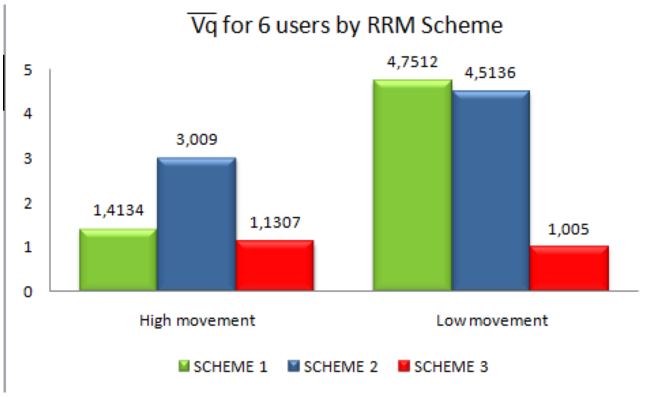

Fig 6. Illustration of the QoE results comparison among different allocation schemes, with 70% of users receiving High Movement Videos (HC) and 30% of users receiving Low Movement Videos (LC). No of users: 6. Display Format SD (a=1) and H.264 (k1= 1.36, k2= 1.93). (Probability good channel= 0.75), T duration= 5 min.

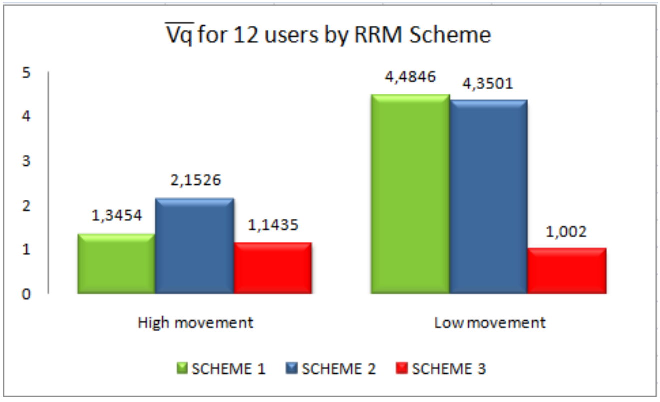

Fig 7. Illustration of the QoE results comparison among different allocation schemes, with 50% of users receiving High Movement Videos (HC) and 50% of users receiving Low Movement Videos (LC). No of users: 12. Display Format QCIF (a=10.8) and H.264 (k1= 1.36, k2= 1.93). (Probability good channel= 0.75), T duration= 5 min.

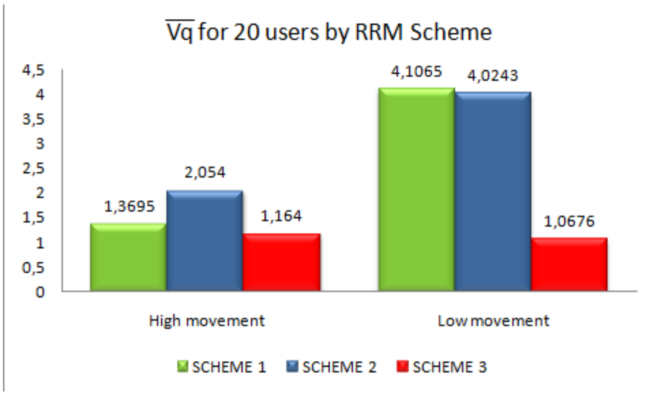

Fig 8. Illustration of the QoE results comparison among different allocation schemes, with 30% of users receiving High Movement Videos (HC) and 70% of users receiving Low Movement Videos (LC). No of users: 20. Display Format QCIF (a=10.8) and H.264 (k1= 1.36, k2= 1.93). (Probability good channel= 0.75), T duration= 5 min.

Results obtained shows a difference between the QoE perceived in MOS terms by users interested on Low movement videos compared with users interested on High movement videos. This behavior is the result of the characteristic of the video. Low movement content videos are less demanding in terms of resource allocation and quality perceived by users. In all cases, the first group of users has a grade over 4, which in MOS terms is associated to a good QoE. The use of the scheme based on the RRM2 shows and improvement in the QoE perceived by users in the network as shown figures 6, 7 and 8. Also, figures 9 and 10 show in more detail the grade of improvement/reduction in the average QoE by kind of user when number of users connected to a BS is increasing showing ΔQoE.

In the same figures is possible to note the reduction in the QoE perceived by both types of users when the RRM3 scheme is applied. The explanation of this phenomenon is associated to the resources allocation always to user with the minimum calculated QoE, or in other words, to users with bad channel conditions. This generates as a result that user with low conditions end up having more resources limiting the overall performance of the system. About users expecting High movement videos, results showed a QoE below the acceptable value for a MOS evaluation. The effect of the variation in the probability to get a good conditions channel over the general QoE average is low.

Although the parameters are the same, it is remarkable the fact of the improvement in the QoE average from the inclusion of this parameter as a factor to distribute the access during the slot time. Noteworthy is the QoE increase between the two scenarios (RRM1 and RRM 2) in the case of users who receive video with high movement content. However, criteria applied until this moment does not allow increasing the QoE average for this kind of users in a value equal to or greater than MOS defined as fair to the quality perceived by the user.

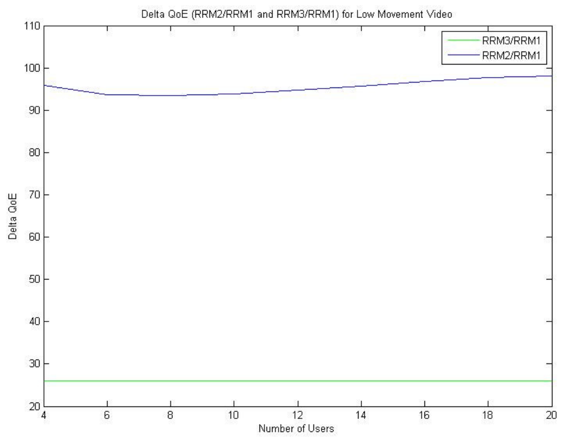

Figure 9. Illustration of the relation of average QoE using RRM1 compared with the average QoE using RRM2. Also, it is represented the relation between average QoE using RRM1 and RRM3. This average corresponds to the evaluation of QoE for Low Movement Videos.

In the case of Low movement videos, although there is a reduction in the QoE average between RRM1 and RRM2, figure 9 show the level of reduction around 5%. However, the application of the scheme shows that this reduction of 5% is compensated by an improvement between 60% and 140% in the QoE evaluation of the high movement videos, depending on the number of users.

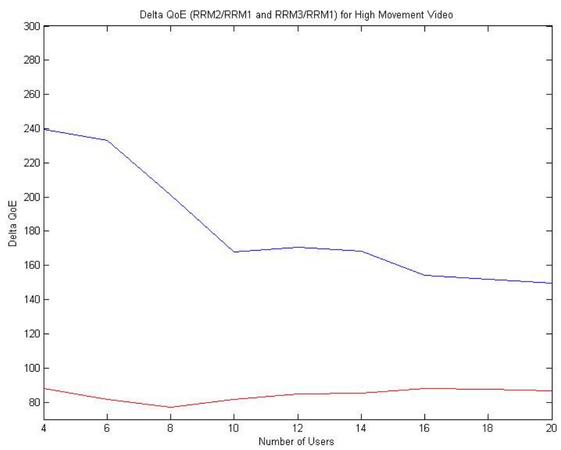

Figure 10. Illustration of the relation of average QoE using RRM1 compared with the average QoE using RRM2. Also, it is represented the relation between average QoE using RRM1 and RRM3. This average corresponds to the evaluation of QoE for High Movement Videos.

CONCLUSIONS AND FUTURE WORK

In this paper, a first approach to a QoE based allocation scheme is proposed. We provided an insight to the effect of QoE as a parameter to define the resource allocation in a wireless network. Variation of user satisfaction criteria has been simulated in order to understand more about the incidence of the QoE as a factor to provide video streaming service.

It can be seen that including QoE information in the resource schedulers (Scheme 2) can lead to an improvement in MOS between 60% and 140%, as compared to standard C/I (Scheme 1) solutions, for the more demanding content type. At the same time, the loss in MOS for the users interested in the other content type is very limited. This indicates that the inclusion of semantic information, e.g. on video quality and/or device screen types, can support the network operator in investing its radio resources where they are more needed and/or where they can impact the most the user service appreciation. However, it is necessary to look for new ways to reach a higher level of QoE considering high movement content and low movement content videos. For the future of the research work, new aspects (i.e. handoff, QoE based policies of access) should be considered. Another interesting topic is the consideration of new types of content in the model definition.

In the initial part we analyze this problem with a basic scenario to get insight of how the QoE might be introduced in a resource management scheme so that users and operators may be benefited in a long term. The results obtained so far allow us to identify an interesting research area, where the definition of SLA based on QoE could be supported.

The stage shown in this paper includes the identification of a model to establish a relation between the bitrate and the MOS results in order to quantify how much is the QoE improved using as a factor to allocate the resources in a wireless network.

The proposed scheme for the resource allocation shows that it is possible to use the QoE factor as a new key element in the improvement of the performance in a network. As part of future work, it is necessary to look for new ways to reach a higher level of QoE for both kinds of users. At the same time, it will be necessary to evaluate the resource allocation schemes presented in this paper in a scenario with more BS and considering the effect of handoff.

REFERENCES

[1] Dyachuk, D; Deters, R. Ensuring Service Level Agreements for Service Workflows, on Proceedings, IEEE International Conference on Services Computing, 2008.

[2] Recommendation Y.110 “Global Information Infrastructure principles and framework architecture". 1998.

[3] “Assuring Quality of Experience for IPTV,” HeavyReading, Whitepaper, July, 2006.

[4] M. Robins, “Delivering optimal Quality of Experience (QoE) for IPTV success”, Spirent Communications, Whitepaper, February, 2006.

[5] M. A. Schwartz, “Enabling a Quality IPTV Customer Experience”, Telcordia, Whitepaper, 2005.

[6] Kilkki, K. Quality of Experience in Communications Ecosystem. Journal of Universal Computer Science, vol. 14, no. 5 (2008), 615-624 Last http://www.jucs.org/jucs_14_5/quality_of_experience_in/jucs_14_05_0615_0624_kilkki.pdf. Last review: October 30 th, 2009.

[7] Bressan, G.; Zapater, M.N.; A Proposed Approach for Quality of Experience Assurance of IPTV, Digital Society, 2007. ICDS '07. First International Conference on the 2-6 Jan. 2007 Page(s):25 – 25.

[8] Pietro Lungaro, Zary Segall and Jens Zander, "Context-aware RRM for Opportunistic Content Delivery in Cellular Networks", in Proceedings of the 3rd international conference on Communication Theory, Reliability and Quality of Service (CTRQ10), Athens, June 2010. (BEST PAPER AWARD WINNER)

[9] A. S. Patrick, et al., "A QoE Sensitive Architecture for Advanced Collaborative Environments," in Proceedings of the First International Conference on Quality of Service in Heterogeneous Wired/Wireless Networks, 2004.

[10] "Assuring Quality of Experience for IPTV," HeavyReading, Whitepaper, July, 2006.

[11] Odadzic, B; Jankovic, M. Open Service Access (OSA) Business Models and Service Level Agreement Aspects. TELSIKS 2003 Serbia and Montenegro, NiS, October 1-3, 2009.

[12] Sourav Pal Mainak Chatterjee Sajal K. Das. A two level Resource Management Scheme in Wireless Networks Based on User Satisfaction. ACM SIGMOBILE Mobile Computing and Communications Review - Special Issue on Medium Access and Call Admission Control Algorithms for Next Generation Wireless Networks 2006.

[13] Joskowicz, Jose, Lopez Ardao, Carlos. A Parametric model for Perceptual Video Quality Estimation. Telecommunication Systems DOI: 10.1007/s11235-010-9352-9. 2010.

[14] T. M. O' Neil, "Quality of Experience and Quality of Service for IP Video Conferencing", Polycom, Whitepaper, 2002.

[15] J. Goodchild, "Integrating data, voice and video – Part II," IP Video Implementation and planning guide, United States Telecom Association, 2005.

[16] D. Lopez, F. Gonzalez, L. Bellido, and A. Alonso, "Adaptive multimedia streaming over IP based on customer oriented metrics," in Proceedings of the Seventh IEEE International Symposium on Computer Networks, 2006, pp. 185-191.

[17] H. Lin, M. Chatterjee, S. K. Das and K. Basu,"ARC: An Integrated Admission and Rate Control Framework for CDMA Data Networks Based on Non-Cooperative Games," Intl. Conference on Mobile Computing and Networking (MobiCom), 2003.

[18] N.B. Mandayam, P.-C. Chen and J.M. Holtzman, Minimum duration outage for cellular systems: a level crossing analysis, Proc. of IEEE VTC, 1996, pp. 879-883.

[19] Y. Mansour, B. Patt-Shamir, "Jitter Control in QoS Networks," IEEE/ACM Transactions on Networking, Vol. 9, No. 4, August 2001, 1998.

[20] S. Pal, M. Chatterjee and S. K. Das, "Improving Guarantees on Delivery Time for Wireless Data Services," IEEE WCNC, Volume: 4, pp. 2539-2544, 2004.

[21] S. Pal, M. Chatterjee and S. K. Das, "User- Satisfaction based Differentiated Services for Wireless Data Networks," IEEE International Conference on Communications (ICC), May 2005.

[22] Y. Snir, Y. Ramberg, J. Strassner, R. Cohen, Policy Framework QoS Information Model, IETF-policyqos- info-model-02.

[23] G.D. Stamoulis, D. Kalopsikakis and A. Kyrikoglou, "Efficient agent-based negotiation for telecommunicationsservices", Global Telecommunications Conference (GLOBECOM), Vol 3. pp. 1989-1996, 1999.

[24] M. Xiao, N.B. Shroff, E.K.P Chong, "Utility-based power control in cellular wireless systems", Proceedings