AHP-based Adaptive Resource Selection for Cognitive Platform in Cloud Gaming Service

Atchara Rueangprathum, Somchai Limsiroratana, and Suntorn Witosurapot

Abstract— **Cloud gaming service enables offloading heavy video-processing tasks up to the cloud server so that simple computers or mobile devices can be eligible to run sophisticated games, but on the expense of high network communications. In this regard, the adequate network utilization must be realized for delivering good gaming experiences to the game players. This necessitates a cognitive platform, which is capable of modifying its multimedia quality requirement in response to the network constraint, and notifying the cloud gaming server for updating the corresponded workload. In this regard, the Analytic Hierarchy Process (AHP) method has been proposed to deploy at the cognitive platform for cloud gaming service to select an optimal resource allocation strategy that satisfies various multimedia requirements and energy-awareness. Experiment results can confirm that the proposed method is flexible to enhance the capability of cloud gaming service in term of more efficient cloud gaming resource utilization, particularly during heavy-congested periods, while players' quality of gaming experience can be still maintained under the mandate of intelligent agent on the player devices.**

Keywords-mobile cloud gaming; cognitive agent; multimedia adaptation; context awareness; AHP

I. INTRODUCTION

Cloud gaming [1] is a kind of cloud service that allows the low-performance computers or mobile devices to run highly sophisticated games. However, due to the intrinsic limitation of rendering the game remotely in the cloud and streaming the scenes as video frames back to the player over the Internet, the cloud gaming service relies intensely on the adequate network availability [2] in order to deliver acceptable user experience in gaming. The issue of multimedia content adaptation is then a prime consideration for achieving two ultimate goals: a) the utmost gaming resource utilization at the server-side, and b) the highest satisfaction level at the player-side. Nonetheless, it is not easy to achieve such requirements by simply relying on a server-centric mechanism and naive gaming devices [3], since the server merely attempts by default to deliver real-time media streaming to a player device at the highest possible quality, in accordance with the notified physical device resolution.

To enrich the default operations in typical cloud gaming, it is required that somewhat of cognition must be existed at the player's device so that the rational tuning of performance parameters at run-time can be enabled. For instance, it can be then possible to make a trade-off between the higher video resolution and the lower bit rate of video transmission, in order to preserve the overall bandwidth usage and the player's satisfaction simultaneously. To date, the realization of this requirement is still an active research in the field of cognitive cloud gaming, where reasoning engine plays a crucial role of evaluating the game player's evironment and deciding on the proper demand of adaptive multimedia contents according to the evaluations and the player's preferences.

In this paper, the local decision-making engine has been modeled at the cognitive device for deriving the user demand in adaptive video playback quality as a multiple-attribute decision-making (MADM) problem under an uncertain environment. Analytic Hierarchy Process (AHP) algorithm has been proposed for dealing with this problem, since it can handle both qualitative and quantitative criteria related to audio/video multimedia resources and the battery-energy level simultaneously. Our key contribution is on the application of AHP method for finding the optimal content determination at cognitive gaming platform that can potentially meet the balance of maximizing its own player's gaming experience and reducing the server workload for involved gaming session altogether.

The rest of the paper is organized as follows. The review of related work is given in Section 2. Then, the framework of user-driven cloud gaming resource utilization is introduced in Section 3, following with a model of user's decision-making problem and its AHP-based solution for yielding the user demand that will maximize user gaming experience at given network constraint. The experimental results on performance evaluation is presented and discussed in Section 4. Finally conclusion of the paper is in Section 5.

II. RELATED WORK

A. Cognitive Resource Allocation in Cloud Gaming

In cloud gaming environment, the local cognitive agent at the gaming device are demanded for altering a passive gaming device into the active one so that the better support of cloud gaming resource provision at the cloud gaming server can be expected. To address this demand, many research studies have proposed solutions contributed to the domain.

DOI: 10.5176/2251-3043_4.4.344

For instance, The work [3] focused on a data-collecting solution on the cognitive gaming platform, where the proposed environment perception procedure enables the local cognitive agent to learn the player's environment in real time and push this information to the server so that the respective gaming service adaptation can be derived in a relaxed manner. Indeed, this useful procedure can be well supported for the case of sophisticated cognitive platform as shown in the other work [4], where elaborated features, e.g. the migration and partitioning of game components, as well as partial offline execution, can be offered.

In addition, the work [5] also focused on cognitive cloud gaming environment and proposed a rather complicated framework, where seven types of agents may be needed for executing and delivering adaptive game contents to the players. In contrast, the work [6] concerned on a simpler solution for improving the server's workload in realistic cloud gaming environment. To fulfil the goal, an extra demand of player's display resolution is required for complementing their hybrid version of trans-coding or trans-rendering processes at the gaming server.

While the aforementioned studies can reduce the workload of gaming video rendering at the server-side on the expense of incurred burden at the players' devices, their mechanisms are much in common on the purely technical consideration. Hence, no means of user involvement are provided for governing preferential resource determination. As a result, their technical-oriented solutions becomes complex inevitably for maintaining the adequate service-quality and may not yield the results that conform to the player's expectation. In contrast, by taking into account the user's requirements and contexts, our proposed algorithm can potentially match to what user needs, since both of the technical parameters and user-concerns are considered altogether.

B. AHP Method for Resolving Network-related Problems

AHP is well-recognized as one of the most extensively used multicriteria decision-making methods in the recent literature review [7]. The dominance [8] is due to the following features:

- Handling both qualitative and quantitative factors in an intuitive manner by structuring them into a hierarchical decision model based on a number of criteria
- Quantifying relative priorities of decision criteria with pairwise comparisons, so that ranking a finite set of alternatives can be possible.
- Detecting inconsistency of data that are inherent in the decision-making process for comparing alternatives.

As a consequence, AHP has been sucessfully applied for giving decisions in various research areas (see [9] for the literature review of selected areas and references therein). In fact, there have been some research works in decision related to web and communication networks as well. For instance, the work [10] suggested how AHP can be used to evaluate the level of user satisfaction based on the user-perceived quality of service (QoS) so that the qualities of service classes in the wireless cellular networks can be known and improved if necessary. In [11] and [12], they advocated on the use of AHP to solve the cloud service selection problem of which decision factors related to user subjective assessment are concerned. It can be noticed that these works are common on applying AHP-based method for decision, but are different on the returned benefit whether it is for the user or the service provider. Unlike our work, the AHP-based decision-making method will be served for a mutual benefit of user and server in the distinctive area of cloud gaming service. It is in the sense that the AHP-based method will assist the game player to select the best content resolution that is satisfy not only their own preference, but also the current network condition. At the same time, the less workload at the game server can be feasible due to the sensible demand of user's content resolution. In addition, our work relies heavily on the combined AHP-mathematical programming approach [13], rather than the standalone AHP, since the relative important weights of alternatives in the AHP process must be calculated further to yield a value of content resolution as a final decision.

III. Optimal Selection of Content Resolution

The methodology given in this section is indeed an optimal resource utilization mechanism that empowers a cognitive platform to make a decision on the optimal content resolution of adaptive multimedia that can maximize gaming experience (regarding the user's policy) under a given network constraint (according to the server's notification) as illustrated in Fig.1. this mechanism is modeled as a MADM problem and manage to solve it through the AHP method so that the weighted values of context-aware parameters (i.e. network bandwidth, screen resolution and power consumption) can be obtained, and used later in an optimal resource allocation problem.

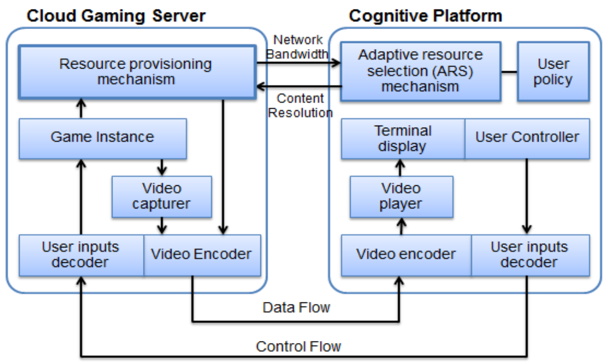

Figure 1. Cognitive resource allocation architecture.

Although many performance metrics can be considered in adaptive cloud gaming contents [5], some of them [14] will be particularly interested as shown in Table I, According to the different viewpoints of application (game), network, and device. Nevertheless, these metrics will need to be managed in such a way that they can be processed by the AHP method of which basic procedure are described below:

TABLE I. PERFORMANCE METRICS UNDER CONSIDERATION

Viewpoint	Performance Metric	Symbol	Unit
Application (Game)	Video resolution	-	pixels
	Video frame-rate	-	fps
	Audio bit-rate	-	kbps
Network	Network bandwidth	BW	Mbps
Device	Screen resolution	SR	pixels
	Power consumption	PW	mWh

A. Modeling a hierarchical analysis structure

When using AHP, it is demanded to define a hierarchical structuring model of the decision-making problem, where the objective, criteria, and alternatives are structured into a hierarchy. As seen in Fig. 2, the proposed model is a three-level hierarchy and can be described as follows: the top-level is the goal of the decision-making problem (i.e. optimal content determination), the mid-level consists of various evaluation criteria (i.e. video frame-rate, video resolution, and audio bit-rate), the bottom-level consists of alternatives (i.e. network bandwidth, screen resolution, and power consumption).

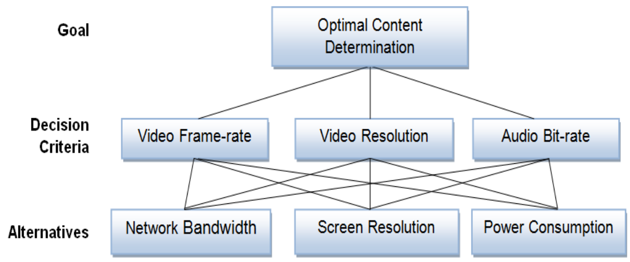

Figure 2. Hierarchical structure of the model.

B. Assigning the weights

AHP can calculate the relative weight of decision criteria and alternatives in an intuitive manner. The basic steps are decribed as follows:

1) Making pairwise comparison: In this step, the relative importance of involved performance metrics are judged by a pairwise comparison. Rating the relative priority of each metric is done by asssigning a value according to Table II [11], for example the value of 1 means equally preferred and 9 means extremely preferred. By working in this manner, the reciprocal matrix can be obtained as shown in Table III.

TABLE II. AHP RATING SCALE OF JUDGMENT

Value	Verbal judgment between pairwised values
1	Equally preferred
3	Moderately preferred
5	Strongly preferred
7	Very Strongly preferred
9	Extremely preferred
2, 4, 6, 8	Between the judgment above

TABLE III. MATRIXES FOR THE 3 ALTERNATIVES FROM EACH CRITERIA

	Video Frame-Rate			Video Resolution			Audio Bit-Rate		
	BW	***SR***	***PW***	***BW***	***SR***	***PW***	***BW***	***SR***	***PW***
BW	1	3	9	1	3	5	1	3	5
SR	1/3	1	5	1/3	1	3	1/3	1	3
PW	1/9	1/5	1	1/5	1/3	1	1/5	1/3	1

Legend: BW: Bandwidth SR: Screen Resolution PW: Power Consumption

2) Computing priority vector for decision criteria: Having a reciprocal matrix, the priority vectors, which are the normalized Eigen vectors of the matrix, can be computed. Here, they can be calculated by using technique of normalized relative weight and the results are shown in Table IV.

TABLE IV. WEIGHTS OF DECISION CRITERIA

Decision Criteria	Weights	Consistency Ratio (CR)
Video Frame-rate	0.637	0.037
Video Resolution	0.258	
Audio Bit-rate	0.104	

3) Checking for consistency: Since the data in a reciprocal matrix may not be consistent. This is due to the imposition of 1 to 9 rating scale of judgment as performed in Step 1. The AHP will check consistency of data in evaluation via a ratio called Concistency Ratio (CR):

$$CR = (CI/RI), \qquad RI = 0.58 \qquad (1)$$

where RI is a random concistency index and the typical values [15] are given in Table V, and n refers to the number of parameters. Since $n = 3$ in this case, RI is then set to 0.58; CI is concistency index, and is defined as

$$CI = (\lambda_{max} - n)/(n - 1) \qquad (2)$$

where λ_{max} is the maximum eigenvalue of the judgment matrix, which is set to 3.0383 in this case.

If the value of CR is smaller or equal to 0.1, then the inconsistency is acceptable. In our case, Table VI shows how the priority vectors and the consistency ratio of the judgment matrix are generated. Noticed that the CR in each decision criteria is less than 0.1, so the judgment matrix is consistent.

4) Computing priority vector for alternatives: Similar to the process in Step 2 of comparing the decision criteria, all pairs of alternatives are now compared using the AHP rating value. Similar to Step 3, a judgment matrix is determined, and priority weights are calculated for each of the alternative. The results are given in Table VII.

TABLE V. RANDOM CONSISTENCY INDEX

n	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

TABLE VI. WEIGHTS OF ALTERNATIVES UNDER EACH CRITERIA

Decision Criteria	Alternatives			Consistency Ratio (*CR*)
	BW	*SR*	*PW*	
Video Frame-Rate	0.671	0.265	0.063	0.027
Video Resolution	0.637	0.258	0.104	0.037
Audio Bit-Rate	0.659	0.156	0.185	0.028

Legend: BW: Bandwidth SR: Screen Resolution PW: Power Consumption

TABLE VII. WEIGHTS OF EACH ALTERNATIVES

Alternatives	Weights (*w*)	Consistency Ratio (*CR*)	Ranking
Network Bandwidth	0.661	0.033	1
Screen Resolution	0.252		2
Power Consumption	0.086		3

Finally, the summary of all the weights in the hierarchy can be illustrated in Fig. 3. It can be noticed that the optimal ratio of factors influencing on the adaptive contents will be largely contributed to the concern of network bandwidth, following with the device resolution and power consumption accordingly.

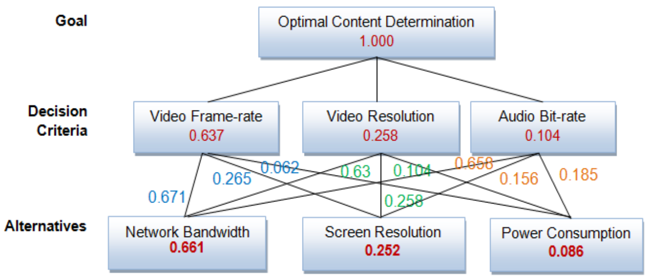

Figure 3. Weighted values of cognitive resource allocation model.

C. Formulating resource allocation problem

Based on the AHP weighted values obtained in the previous step, they can be used to calculate the value of required content resolution that satisfies our requirement. However, the possible values will be preferably specified in discrete values following the list of common graphics display resolution[1], as shown in Table VIII. In the other word, the output video resolution is classified into 5 levels, ranging from the ultra low to the very high video resolutions. The direct advantage is on the ease of manipulation by the proposed mechanism, since the effective bandwidth utilized for content adaptation is rather in a stepwise fashion. The indirect advantage is on the ease of User Interface (UI) implementation, since only a set of limited choices will be displayed for allowing users to have a fast selection.

TABLE VIII. 5 LEVELS OF AVAILABLE CONTENT RESOLUTION

Level	Video resolution	Pixels
1. Ultra Low (UL)	640 x 480	307,200
2. Low (L)	1280 x 720	921,600
3. Medium (M)	1600 x 900	1,440,000
4. High (H)	1920 x 1080	2,073,600
5. Very High (VH)	2048 x 1152	2,359,296

[1] https://wikipedia.org/wiki/Graphics_display_resolution

To compute the value of optimal video resolution, which is the product of AHP weighted values (i.e. benefits) of the bottom-level (alternatives) and the incurred cost of them, the method is as follows:

$$x = \sum_{i=1}^{n} w_i c_i \quad (3)$$

where x is the required content resolution, w_i is the weight of alternative i (referring to the Table VII), n is the number of alternatives and c_i is the cost of alternative i that is reflected by the following equation:

$$c_i = \frac{r_j}{m_j}, j = 1,..,5 \quad (4)$$

where r_j is the required resource, m_j is the maximal availability of that resource, and j is the number of level ranging from 1 to 5 according to the levels specified in Table VIII.

In this paper, the cost of each alternative can be calculated as follow:

1) Network bandwidth: The cost is an inverted ratio of the network's current capability to fulfill the user's requirements and hence includes both the user's required bandwidth (r_j), as well as the network's available bandwidth (m_j). In order to obtain the r_j, the simple experiment is conducted to observe the bandwith consumed by j multimedia streams with different resolutions given in Table VIII. Then, the cost incurred by the deliveries of different adaptive streams in a variety of network technologies[2], i.e. 2G-Edge (16 Mbps), 3G (16 Mbps), 3G (42 Mbps), 4G (42 Mbps), and 4G-LTE (100 Mbps) can be summarized as shown in Table IX.

TABLE IX. THE COSTS OF BANDWIDTH FOR DELIVERING TARGET CONTENT RESOLUTIONS IN VARIOUS NETWORK TECNOLOGIES

r (Mbps)	Cost on various network types				
	m ***(1.6 Mbps)***	***m*** ***(14.4 Mbps)***	***m*** ***(21.0 Mbps)***	***m*** ***(42.0Mbps)***	***m*** ***(100 Mbps)***
7.92	4.95	0.55	0.38	0.19	0.08
12.64	7.90	0.88	0.60	0.30	0.13
18.32	11.45	1.27	0.87	0.44	0.18
27.92	17.45	1.94	1.33	0.66	0.28
42.56	26.60	2.96	2.03	1.01	0.43

Experiment: H.264 encoded and 60-fps video streaming, 3.5 GHz 6-core server and Gigabit network

2) Screen resolution: The cost is the ratio of the desired content resolution (r_j) and the screen resolution (m_j). Here, the costs incurred by the deliveries of adaptive streams at different resolutions can be summarized in Table X.

[2] https://wikipedia.org/wiki/Comparison_of_mobile_phone_standards

TABLE X. THE COSTS OF SCREEN RESOLUTIONS FOR DELIVERING TARGET CONTENT RESOLUTIONS

r (pixels)	Cost on various screen resolutions				
	m (307,200 pixels)	*m* (921,600 pixels)	*m* (1,440,000 pixels)	*m* (2,073,600 pixels)	*m* (2,359,296 pixels)
307,200	1.00	0.33	0.21	0.15	0.13
921,600	3.00	1.00	0.64	0.44	0.39
1,440,000	4.69	1.56	1.00	0.69	0.61
2,073,600	6.75	2.25	1.44	1.00	0.88
2,359,296	7.68	2.56	1.64	1.14	1.00

3) *Power consumption:* The cost is a ratio of the power consumption needed to transmit the desired content resolution and the battery-power life. Here, the energy measurement setup and experimental results are assumed as given in [16] to support our pilot study so that the relationship of the power consumption for different resolutions can be feasibly derived. In this regard, the power consumption (r_j) in each j level according to the given values in Table VIII can be computed. However, the capacity of battery (with the 20% safty factor) is devided into 5 levels. Therefore, in a case of the battery with 1650 mAh and 3.7 volt specification, the maximum power consumption (m_j) of the battery in each j level can be computed and summarized in Table XI.

TABLE XI. THE COSTS OF POWER CONSUMPTIONS FOR DELIVERING TARGET CONTENT RESOLUTIONS

r (mWh)	Cost on various power consumptions				
	m (976.80 mWh)	*m* (1953.6 mWh)	*m* (2930.00 mWh)	*m* (3907.00 mWh)	*m* (4884.00 mWh)
876.00	4.95	0.55	0.38	0.19	0.08
912.87	7.90	0.88	0.60	0.30	0.13
943.97	11.45	1.27	0.87	0.44	0.18
981.99	17.45	1.94	1.33	0.66	0.28
999.13	26.60	2.96	2.03	1.01	0.43

IV. EXPERIMENTAL EVALUATION

In order to evaluate the efficacy of the proposed method, an example of its application is considered in a simple network scenario, where a number of clients are concurrently connecting to a server for cloud gaming service consumption. Our evaluation is on the conformance of the user's expectation and the actual allocation occurred in different cases of network bandwidth and power resource availability.

A. *Plentiful resource environment*

It is a situation where the network is under-utilized and the the player's battery-power level is high. In this case, the player will tend to recieve whatever content resolution it desires. As shown in Table XII, the player who demands a "very high (VH)" screen resolution will be granted with the "very-high (VH)" content resolution (i.e. the highlighted line) as desired.

TABLE XII. SUMMARY OF CASES IN OVER-UTILIZED NETWORK

BW=H, SR=VH, PW=VH	Alternatives (W_iC_i)			Total score (x)
	BW	***SR***	***PW***	
UL	0.125	0.033	0.015	0.173
L	0.199	0.098	0.016	0.313
M	0.288	0.154	0.017	0.459
H	0.439	0.221	0.017	0.678
VH	0.670	0.252	0.018	0.939

B. *Scarce resource environment*

In a contrast situation, the network is over-utilized and the role of content adaptation becomes crucial. The player, however, may be assigned with the much lower level of content resolution than the desired one, unless the availability of network bandwidth are adequate. Based on the data given in Table XIII, the user in case 1, who demands the "very high (VH)" screen resolution, will get merely the "Low (L)" content resolution, due to the low availability of both network bandwidth and battery power. Since the BW alternative has a much higher weight than the other alternatives (refering to Table VII), the influence of PW alternative is rather limited in all cases. It is obvious in the case 2 and 3, where the influence of BW is dominant. The best selection of suitable content resolution can be issued, according to the best-maximum value below the value 1 (i.e. the upper boundary of feasible case) of the total score in all cases as shown in Table XIV – XVI.

In order to illustrate the clear advantages of our proposed method over the method found in traditional remote-rendering cloud gaming, the experiments have been performed (in a network scenario as described in [6]), to investigate the performance in terms of utilization cost and saving cost of both cases. As shown in Fig. 4, the lower utilization cost can be attained in our case, due to the less, but sufficient, demanding of network bandwidth, and hence less power consumption, at the gaming device. As a consequence, by subtracting the values compared in both cases, the saving cost for network bandwidth utilization and power consumption can be illustrated in Fig. 5.

TABLE XIII. SUMMARY OF CASES IN OVER-UTILIZED NETWORK

	Availability			Result (x)
	BW	***SR***	***PW***	
Case 1 (Table XIV)	L	VH	L	L
Case 2 (Table XV)	L	H	VH	L
Case 3 (Table XVI)	H	VH	UL	H

TABLE XIV. CASE 1

BW=L, SR=VH, PW=L	Alternatives (W_iC_i)			Total score (x)
	BW	***SR***	***PW***	
UL	0.36	0.03	0.04	0.43
L	0.58	0.10	0.04	0.72
M	0.84	0.15	0.04	1.04
H	1.28	0.22	0.04	1.55
VH	1.95	0.25	0.04	2.25

TABLE XV. CASE 2

BW=L, SR=H, PW=VH	Alternatives (W_iC_i)			Total score (x)
	BW	***SR***	***PW***	
UL	0.364	0.125	0.015	0.504
L	0.580	0.199	0.016	0.795
M	0.841	0.288	0.017	1.146
H	1.282	0.439	0.017	1.738

VH	1.954	0.670	0.018	2.641

TABLE XVI. CASE 3

BW=H, SR=VH, PW=UL	Alternatives (W_iC_i)			Total score (x)
	BW	*SR*	*PW*	
UL	0.125	0.033	0.077	0.235
L	0.199	0.098	0.080	0.378
M	0.288	0.154	0.083	0.525
H	0.439	0.221	0.086	0.747
VH	0.670	0.252	0.088	1.010

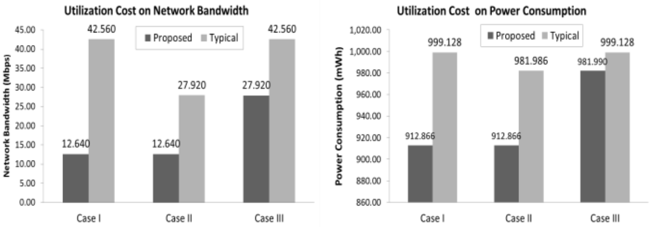

Figure 4. Utilization cost comparison in a) BW and b) PW experiments

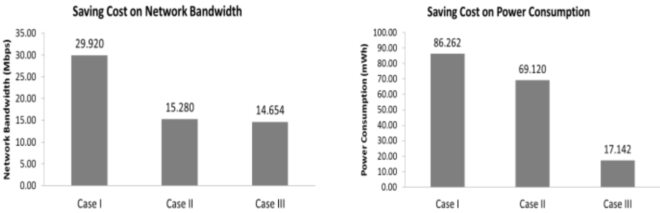

Figure 5. Saving cost consideration in a) BW and b) PW experiments

V. CONCLUSION

In this paper, the notable use of local computing facility is encouraged to give mutual benefits for player and server in cloud gaming service. By enabling the AHP-based decision-maker at the gaming device, the player's benefit in term of reasonable demands for adaptive resource under dynamic network availablity can be issued, due to the hierarchical analytic decision upon the different criteria, and alternatives. At the same time, the server's benefit in term of the improved gaming workload of a certain session can be realized. Our experimental results can confirm the validity of the proposed method, which is remarkably simple and flexible for enabling cognitive resource utilization in the cloud gaming environment.

REFERENCES

[1] R. Shea, J. Liu, E. C.-H. Ngai, and Y. Cui, "Cloud gaming: architecture and performance," *IEEE Network*, vol. 27, no. 4, pp. 16–21, Jul. 2013.

[2] W. Cai, M. Chen, and V. C. M. Leung, "Toward Gaming as a Service," *IEEE Internet Computing*, vol. 18, no. 3, pp. 12–18, May 2014.

[3] W. Cai, C. Zhou, V. C. M. Leung, and M. Chen, "Environment Perception for Cognitive Cloud Gaming," in *Cloud Computing*, V. C. M. Leung and M. Chen, Eds. Springer Int. Publishing, 2013, pp. 3–13.

[4] W. Cai, C. Zhou, V. C. M. Leung, and M. Chen, "A Cognitive Platform for Mobile Cloud Gaming," in *2013 IEEE 5th Int. Conf. on Cloud Computing Tech. and Sci. (CloudCom)*, 2013, vol. 1, pp. 72–79.

[5] C. Hull, C. Darryl, M. Philip and P. Gerard, "FRAGED: A Framework for Adaptive Game Execution and Delivery to Improve the Quality of Experience in Network Aware Games," In Proc. of PGNET'14, Liverpool (UK), June 2014.

[6] R. Jitpukdeebodintra and S. Witosurapot, "Hybrid Method for Adaptive Cloud Gaming Contents," *GSTF Journal on Computing (JoC)*, vol. 4, no. 2, Mar. 2015.

[7] C. Kahraman, S. C. Onar, and B. Oztaysi, "Fuzzy Multicriteria Decision-Making: A Literature Review," *Int. J. of Computational Intelligence Systems*, vol. 8, no. 4, pp. 637–666, Jul. 2015.

[8] C.-C. Chou and K.-W. Yu, "Application of a New Hybrid Fuzzy AHP Model to the Location Choice," *Mathematical Problems in Engineering*, vol. 2013, pp. e592138, Jun. 2013.

[9] O. S. Vaidya and S. Kumar, "Analytic hierarchy process: An overview of applications," *European J. of Operational Research*, vol. 169, no. 1, pp. 1–29, Feb. 2006.

[10] C.E. Otero, I. Kostanic, L. Otero and L. Meredith, "Characterization of user-perceived quality of service (QoS) in mobile devices using network pairwise comparisons, " *Int. J. of Wireless & Mobile Networks*, vol. 2, no. 3, pp. 141–153, Aug. 2010.

[11] M. Godse and S. Mulik, "An Approach for Selecting Software-as-a-Service (SaaS) Product," in *IEEE Int. Conf. on Cloud Computing, 2009. CLOUD '09*, 2009, pp. 155–158.

[12] S. K. Garg, S. Versteeg, and R. Buyya, "SMICloud: A Framework for Comparing and Ranking Cloud Services," in *2011 Fourth IEEE Int. Conf. on Utility and Cloud Computing (UCC)*, 2011, pp. 210–218.

[13] W. Ho, "Integrated analytic hierarchy process and its applications – A literature review," *European Journal of Operational Research*, vol. 186, no. 1, pp. 211–228, Apr. 2008.

[14] M. N. Ismail, R. Ibrahim, and M. F. Md Fudzee, "A Survey on Content Adaptation Systems towards Energy Consumption Awareness," *Advances in Multimedia, Advances in Multimedia*, vol. 2013, pp. e871516, Jul. 2013.

[15] T. L. Saaty, "Decision making with the analytic hierarchy process," *Int. J. of Services Sciences*, vol. 1, no. 1, pp. 83–98, Jan. 2008.

[16] I. Ghergulescu, A.-N. Moldovan, and C. H. Muntean, "Energy-aware Adaptive Multimedia for Game-based e-learning," in *2014 IEEE Int. Sym. on Broadband Multimedia Systems and Broadcasting (BMSB)*, 2014, pp. 1–6.

AUTHORS' PROFILE

Atchara Rueangprathum was born in Songkhla province, Thailand on September 8, 1977. She completed a Bachelor degree in Business Administration (Information Systems) from Rajamangala Institute of Technology, Thailand in 2000 and a Master of Science degree in Management of Information Technology from the Prince of Songkla University in 2005. Currently, she is a Ph.D student of Department of Computer Engineering, Faculty of Engineering, Prince of Songkla University, Thailand. Her current research interests include mobile learning and intelligent web technology.

Somchai Limsiroratana was born in the southern of Thailand on December 20, 1969. He holds a bachelor's degree in Electrical Engineering from the Faculty of Engineering, Prince of Songkla University, Thailand. Master and doctor degree in Agricultural Science from the Division of Environmental Science and Technology, Kyoto University, Japan, with the thesis topics related to detect the positions of papaya in natural conditions.

He has been working as a senior lecturer of the Department of Computer Engineering, Faculty of Engineering, Prince of Songkla University (Hatyai campus). His research interests are agricultural image processing, medical image processing, digital watermarking and AI.

Suntorn Witosurapot is an Assistant Professor in department of Computer Engineering, Faculty of Engineering, in Prince of Songkla University (PSU), HatYai, Thailand. He received the bachelor and Master degrees in Electrical Engineering from PSU, Thailand and Ph.D. degree from Swinburne University of Technology, Melbourne, Victoria, Australia, with the thesis topics related to resolving network resource competition in the Internet.

His research interests include Web engineering and applications, model-based software engineering, and Management of Information technology. Currently, most of his research work revolves around Information engineering in smart home network environment and smart grid infrastructure