Resource Allocation for Massively Multiplayer Online Games using Fuzzy Linear Assignment Technique

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Abstract-**This paper investigates the possible use of fuzzy system and Linear Assignment Problem (LAP) for resource allocation for Massively Multiplayer Online Games (MMOGs). Due to the limitation of design capacity of such complex MMOGs, resources available in the game cannot be unlimited. Resources in this context refer to items used to support the game play and activities in the MMOGs, also known as in-game resources. As for network resources, it is also one of the important research areas for MMOGs due to the increasing number of players. One of the main objectives is to ensure the Quality of Service (QoS) in the MMOGs environment for each player. Regardless, which context the resource is defined, the proposed method can still be used. Simulated results based on the network resources to ensure QoS shows that the proposed method could be an alternative.**

I. INTRODUCTION

The games and interactive entertainment industries have grown tremendously in recent years. With the ever increasing demand from the players, designing and producing games has become a complex task. This is especially true for Massively Multiplayer Online Games (MMOGs). "*It is widely unknown and sometimes difficult to comprehend, but massively multiplayer online games (MMOGs) are one of the most technologically complex projects currently undertaken by mankind*" [1]. Besides the technological aspect, the increase complexity of the game design for MMOGs is also difficult to handle. These games are highly interactive due to the nature to handle massive players at the same time. In order for the games to be responsive and stable, MMOGs rely heavily on the reliable interaction infrastructure. As designing and producing MMOGs is a highly complex task, in this paper, we are only focusing on the resource allocation for MMOGs. There are two broad areas where the resources can be defined under. One is related to the design patterns [2] and the other to the networking [3].

Due to the limitation of design capacity of such complex MMOGs, resources available in the game cannot be unlimited. Resources in this context refer to items used to support the game play and activities in the MMOGs, also known as in-game resources. Examples of in-game resources for a strategy game can be the gold, oil, units, and land area. Examples of in-game resources for a First-Person Shooter game can be the ammunition, health and weapon. All these resources are provided using design patterns to decide when to release them to the players. Resource management and allocation in this context is used mainly to manage and improve the game play experiences. Castronova used the economic concepts of scarcity of resources to manage the "fun" factor on MMOGs [4]. This can also fit into the perspective of game designers. Instead of designing massive "basic resources" for most of the players in MMOGs, game designer can work on "shared resources". These shared resources can then be allocated to the players using some kind of assignment algorithms [2].

As for network resources, it is also one of the important research areas for MMOGs due to the increasing number of players. One of the main objectives is to ensure the Quality of Service (QoS) in the MMOGs environment for each player. Another area of resource allocation for MMOGs is the management of the network servers [5].The objectives of many multi-player/users environment normally aim to provide efficient and fair allocation of network resources so that the QoS will not be compromised. This is also related to the theory of scarcity of resources.

Regardless which type of resources in MMOG is of interest, this problem can be viewed as assignment problem. In this paper, it is known as resource allocation problem. Technically, this could also be referred as a linear assignment problem (LAP) [6], where in an instance of LAP, a $m \times n$ matrix of assignment entries is given, with each entry indicating the cost value of one of the m resources for one of the n requests. Thus, optimal resource allocation to satisfy as much game players in MMOG can simply be solved by treating it as a linear assignment problem. However, any linear assignment method normally based on a single performance criterion, is practically limited since this fails to incorporate not only other important considerations (e.g. resource utility), but also the vagueness that is inherent in these considerations. Linear assignment with multiple criteria like those in the MMOG is normally a difficult task, especially when we have clearly conflicting criteria, there is normally no optimal solution simultaneously satisfying all the criteria. Besides,

some criteria are easily formulated with words but cannot easily be cast as concise formulas.

To incorporate these considerations while retaining the simplicity, we examine the use of fuzzy system [7] to determining the cost entries. These cost entries can be "aggregated" with multiple criteria incorporating human knowledge or some common sense rules. It is therefore the purpose of this paper to examine the possible use of the theory from fuzzy system as well as LAP to perform efficient resource allocation for MMOG.

II. FUZZY SYSTEM AND LAP

In this paper, the combined technique from the proposed fuzzy system and LAP is termed as Fuzzy Linear Assignment Problem (FLAP). Our FLAP can be viewed as an extension of the conventional LAP (CLAP) for dealing with the multi-criteria nature of many assignment problems and can be stated as follows. Let

$$T = \{t_0, t_1, ..., t_{nT}\} \text{ and } R = \{r_0, r_1, ..., r_{nR}\} \quad (1)$$

denotes a set of requests and resources respectively and let

$$c_{ij} = c[t_i, r_j], \text{ for } t_i \in T, r_j \in R \quad (2)$$

be a measure of cost value of answering the request $t_i \in T$ to resource $r_j \in R$. Each cost value c_{ij} is a fuzzy "aggregation" of multiple criteria. Let

$$A = \{a_0, a_1, ..., a_k\} \quad (3)$$

be the set of k attributes, e.g. the in game resources for MMOG, each attribute can be a crisp or linguistic variable and let

$$Rule = \{R_1, R_2, ...R_n\} \quad (4)$$

be the set of fuzzy *if...then* rules which represent criteria for the request. Each rule is of the following form:

*R_i: if a_{i1} is V_{i1} **and/or** a_{i2} is V_{i2}...**and/or** a_{ini} is V_{ini}*
***then** allocation is U_{Ri}* $\quad (5)$

where $a_{ij} \in A$, V_{ij} ($j=1...n_i$) is a crisp value if a_{ij} is a crisp variable or a fuzzy term if a_{ij} is a linguistic variable and U_{Ri} is the output fuzzy set of R_i. Essentially, each rule can be represented by a fuzzy relation and is defined as:

$$R_i(a_{i1}, a_{i2}, ..., a_{ini}) = V_{i1} \times V_{i2} \times ... \times V_{ini} \rightarrow U_{Ri} \quad (6)$$

Assume only *and* connective is used in fuzzy rules, (6) can be rewritten as:

$$R_i(a_{i1}, a_{i2}, ..., a_{ini})$$
$$= [V_{i1}(a_{i1}) \wedge V_{i2}(a_{i2}) \wedge ... \wedge V_{ini}(a_{ini})] \rightarrow U_{Ri}(cost)$$
$$= V_{Ri}(A) \rightarrow U_{Ri}(cost) \quad (7)$$

in which, $\wedge$ is the connective *and* operator. For a specific assignment context A_0, the degree of matching a rule's antecedents is define as:

$$V'_{Ri} = V_{Ri}(A_0) \quad (8)$$

The consequence fuzzy output U'_{Ri} is nothing else but the image of $V_{Ri}(A) \rightarrow U_{Ri}(cost)$ on V'_{Ri}:

$$U'_{Ri} = V'_{Ri} \circ Ri \quad (9)$$

An aggregated fuzzy set of all the output sets can be defined as:

$$U = Agg(U_{R1}, U_{R2}, ..., U_{Rn}) \quad (10)$$

where *Agg* is the aggregation operator and is chosen based on requirements of particular problem in resource allocation. The commonly used operators are *sum* and *maximum.*

Each aggregated cost value c_{ij} in (2) is a function from the fuzzy output space defined in (10) into a space of crisp values:

$$c_{ij} = defuzzifier(U) \quad (11)$$

Assume $N_T < N_R$, the objective of the resource allocation is to find a particular mapping:

$$\prod : T \mapsto R \text{ such that for } t_i, t_j \in T,$$
$$i \neq j \text{ implies that } \prod(t_i) \neq \prod(t_j) \quad (12)$$

such that the total aggregated cost value

$$C_{TOT} = \sum_{i=1}^{N_T} c[i, \prod(i)] \quad (13)$$

is minimised over all possible resource allocation sets induced by $\prod$.

The process described in (6-9) is called fuzzy inference or fuzzy reasoning. The fuzzy output set of each rule is deduced based on given inputs which match the antecedents of that fuzzy rule to some degree. The compositional rule of inference or generalized modus ponens described in (9) is the most commonly used fuzzy reasoning process. Intuitively, the condition specified in (12) is to ensure that no two different tasks are assigned to the same resource and vice-versa. Essentially, the FLAP includes two main steps:

1. define the aggregated cost value using fuzzy reasoning process, as described in (3-11).
2. perform resource allocation, as described in (12-13)

III. FLAP RESOURCE ALLOCATION

A scenario of resource allocation for MMOG using the FLAP can be described as follows. The server receives request from game players. Each game player will be identified geographically in term of the location as well as the maximum number of the resources at that location. As this demand fast reaction, assigning task will normally be performed in real-time. In MMOG environment, it is often the case that there are more than one requests arriving at the same time. Assuming that at time t, there are m requests pending and n resources idle. The resource allocation manager should find an assignment that matches each available game resource to a request, subject to the following multiple criteria: a balance allocation (i.e. fair) among players, short average reaction time, and short average distance between the player and the resource stored. In the game resource allocation problem, the assignment context A in (3) is basically a set of attributes representing information about player and the traffic network at a particular moment such as positions and traffic density. This has direct effect on how fast a game resource can be allocated to the player. The structure of the game resource allocation applying FLAP consists of two main modules as shown in Figure 1.
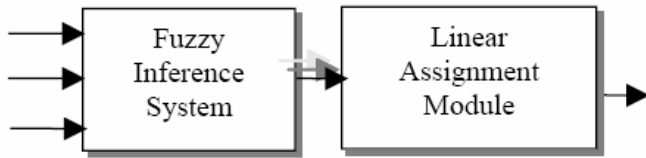

Figure 1. Example of Resource Allocation Manager with three attributes.

The Fuzzy Inference System (FIS) addresses the first step of the proposed FLAP approach and the Linear Assignment Module (LAM) solves the second step. Within this FLAP framework, the attribute of human reasoning and decision making can be formulated by simple *if...then* rules coupled with easily understandable and natural linguistic representations. The linguistic values in the rule antecedents convey the imprecision associated with measurements such as the distance between two locations. Whereas, the linguistic values in the rule consequences represent the vagueness inherent in the reasoning process to generate each cost entry, based on which the assignment decision is made.

The main goal of a fuzzy rule-base system is emulating a human expert and representing various criteria of the resource allocation problem. In this situation, the knowledge of the human operator would be put in the form of a set of fuzzy linguistic rules. The development of rules is time-consuming since expert knowledge is translated into fuzzy rule. However, there are some fuzzy rules extraction techniques and it is out of the scope of this paper. Table 1 illustrates an example of the fuzzy rule-base containing twelve essential rules for the scenario of the resource allocation problem discussed earlier. The form of each rule has been specified in (5) using only connective *and*. In this example, we use *distance, utilization, time_ratio* as the three linguistic variables and *cost* is the output variable for the allocation. It is important to note that

when *distance* changes one step, for example from *near* to *medium*, or when *time_ratio* changes one step from *small* to *big*, *cost* changes two steps, for example from *extremely low* to *low*.

Whereas when *utilization* changes one step, *cost* also changes one step. This is to highlight that *distance* and *time_ratio* are of higher importance than *utilization*. This comes from the fact that any MMOG company will put its profit and its players' satisfactory in the first order. Only when these two criteria are satisfied, the company will consider then consider other factors.

TABLE I
THE FUZZY RULES BASE

distance	utilization	time_ratio	Cost
near	low	Small	Very low
		Big	below average
	high	Small	Low
		Big	Average
Medium	low	Small	below average
		Big	above average
	high	Small	Average
		Big	High
Far	low	Small	Average
		Big	High
	high	Small	above average
		Big	Very high

The main goal of almost all resource allocation is to maximize service quality. For illustration in this paper, three attributes are chosen: distance, time_ratio and utilization. These are actually three linguistic input variables for the FIS. Distance is simply the distance between the player's location to the server that store the game resource and the distance traveled for the game resource to the player location by ensuring the QoS. Time_ratio is the ratio between the time taken to travel to destination under current network traffic condition and that under light network traffic load condition. A big time_ratio reflects a heavy network traffic condition. Finally, utilization of a game resource at time is defined as

$$Utilization(i) = \frac{\text{no. of times the resource } i \text{ is used}}{\text{total no. of requests}} - \frac{1}{N}$$

where N is the number of game resources available from that location. This parameter is considered to make sure a fair allocation of game resources among the players within some geographical locations.

An essential step in developing a fuzzy inference system is to identify relevant states of linguistic variables by a set of linguistic terms with the corresponding fuzzy sets. The shape of a membership function could be of any function. However, for computational efficiency and ease of data acquisition

trapezoidal and triangular membership functions were used in this paper.

IV. SIMULATIONS

A simulation program is developed to provide various emulations of the actual network traffic conditions. We try to simulate the different traffic conditions including light, medium and heavy network traffic load for MMOG. For empirical comparison purposes, we carried out experiments for both the FLAP and CLAP approaches under the same resource allocation situation and network traffic conditions. For the CLAP approach, we take the distance of the shortest path between the game resource's current location and the player as a cost entry, hence the approach is also called "Nearest Neighbourhood" or "nearest" for short. In each resource allocation task, 20 game resources for 10 new requests from players were considered. It was carried out in two conditions: *light* and *heavy* network traffic load.

Simulation data generated were evaluated based on two performance measures for this study: average trip time (the reaction time) and the maximum number of requests which are served by each game resource and deviates from the average number of requests. The objectives are to keep the reaction time in real time and ensure QoS. The last measure requires some clarification: it provides an indication of the relative utilization of a game resource among the players; the smaller its value, the more balanced its utilization is relative to the other game resource for the players. This is to ensure that most game players are served almost fairly, i.e. giving equal chance of utilizing the game resource. Among the above measures, the average trip time is of higher importance than maximum deviation.

Figure 2 shows that the average trip time during light network traffic condition, in the case of the FLAP approach is slightly smaller from about 2 to 5 msec per trip than in the case of CLAP. These results can be explained as follows: when the network traffic load is light, the shortest path usually is the fastest path. Therefore, a significant difference cannot be observed in this case. As for utilization during light network traffic condition as shown in Figure 3, the FLAP approach outperforms CLAP and always results in a more balanced allocation since the maximum number of requests, which is served by one game resource and deviates from the average number of requests, is small.
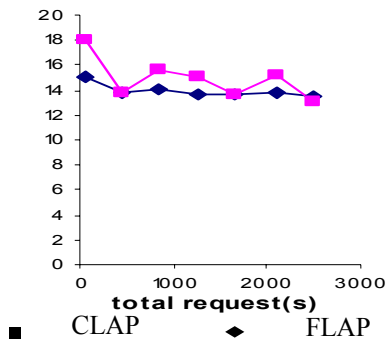

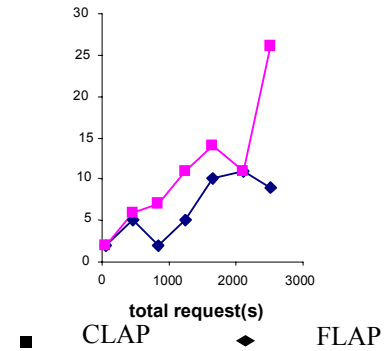Figure 2. Trip time (in msec) during light network traffic condition.

Figure 3. Utilization during light network traffic condition.

The improvements of the proposed approach can be seen clearly in the case when the network traffic is heavy. This could be the normal operation case when MMOG is run. In the CLAP approach, a requested game resource always follows a pre-planned path, which is the shortest path; no matter how heavy is the network traffic density of that path. Thus, when network traffic load is heavy, it is expected that this approach always results in a much longer average trip time. See Figure 4. You could observe that there is a significant improvement.
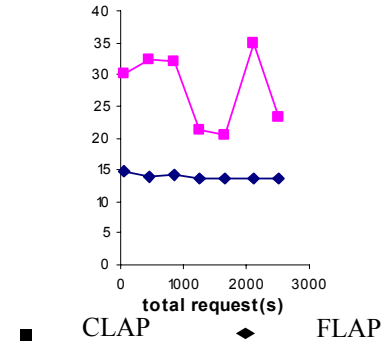

Figure 4. Trip time (in msec) during heavy network traffic condition.
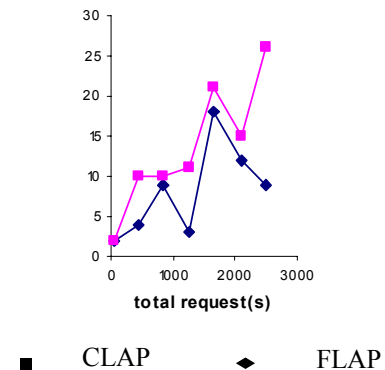

Figure 5. Utilization during heavy network traffic condition.

V. CONCLUSIONS

This paper has presented a FLAP approach to perform resource allocation for MMOG. This approach allows the incorporation of multiple criteria expressed with fuzzy rules,

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and hence admitting vagueness in decision-making that is a natural characteristic of human dispatching expertise. The behaviour of the system can be easily understood by human and knowledge can also be added easily. A simulation experment is carried out to perform resource allocation under different network conditions. Results show that the proposed technique can be an alternative for resource allocation. One can infer that the FLAP approach can be extended to provide effective solutions to other resource allocation scenerios.

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