Reputation-based Multiplayer Fairness for Ad-hoc Cloudlet-assisted Cloud Gaming System

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***Abstract*—Cloud gaming systems host the game in the cloud, and stream players' gaming videos to the terminals in the form of encode video frames. To address the high bandwidth issue of real-time gaming video transmission, a cloudlet-assisted multiplayer cloud gaming system was proposed to encourage cooperative video sharing via a secondary ad-hoc network, on the purpose of exploiting the similarities of video frames among multiple players in a same game. However, the video cooperative sharing among players also introduces fairness problems. In this paper, we complete the ad hoc cloudlet-assisted cloud gaming system by further considering the mobility of terminal devices and the diversity of network quality for distinct players. With mathematical formulation, we study the players' behavior in cooperative sharing patterns and propose a reputation-based multiplayer fairness scheme in terms of frame encoding. Experimental results illustrate the impact of mobility on the system performance and evaluate that the proposed solution provides better fairness gaming ecosystem compared to the existing platform.**

I. Introduction

Video game industry, driven by strong mobile gaming and video game console and software sales, has a major impact on the economy. With the development of cloud computing technology and its novel concept of providing Everything as a Service (EaaS)[1], an opportunity of the game empire revolution is knocking the door of new era. Recently, there have been increasing interests from researchers, system designers, and application developers on the emerging research topic of cloud gaming [2], which transforms the traditional gaming software into Gaming as a Service (GaaS) [3]. In contrary to conventional video game business, the cloud gaming model exhibits several unique advantages: i) *Scalability*: it overcomes the hardware constraints of gaming terminals, including processing capacity, data storage and battery in mobile devices; ii) *Cost-effective*: it reduces the production cost with a unified development approach; iii) *Ubiquitous and Multiple-platform Support*: it provides cross-platform and seamless gaming experience; iv) *Effective Anti-Piracy Solution*: it transforms the game developing companies to game service providers, while provisioning a potential solution to the troublesome piracy problems; vi) *Click-and-Play*: it supports a play-as-you-go mode, in which the players start their gaming sessions without downloading and setting up the game copies. vii) *Energy Efficiency*: it has strong potentials in bringing longer battery life for the mobile terminals and longer gaming times for the players, by offloading game programs' high computational complexity to the cloud. Therefore, not only the academia, but also the industry raise great expectations on the development of cloud gaming solutions. Therefore, pioneering game companies such as OnLive[1] and Gaikai[2], G-Cluster[3], start to provide commercialized GaaS to the public. As a Remote Rendering GaaS (RR-GaaS), as known as gaming-on-demand model, the game service providers host their video games in cloud servers and stream the players' gaming video frames to their terminals over the Internet. In reverse, the interaction from game players are transmitted to the cloud server over the same network [4]. In this context, the cloud intrinsically becomes an interactive video generator and streaming server, while the users' terminals function as the event controllers. With this approach, the cloud gaming service enables the players to run sophisticated games despite the capacity of their restricted hardware, at the expense of higher energy consumption in communications and network. It is obvious that the workload of gaming video rendering in the cloud is extremely heavy, and the video frame transmissions via Internet also incur huge amount of networking resource consumption that leads to high response delay[5][6]. Even though there has been plenty effort on optimize the RR-GaaS system [7], constrained by existing networking infrastructure and charging policy for mobile networks, the age of gaming-on-demand is yet to come.

To solve the problem, a cloudlet-assisted cloud gaming system [8] is proposed to explore the correlations among players' gaming video. Inspired by the idea of peer-to-peer sharing between multiple players in the same game, the authors propose a multi-player cloud gaming system with cooperative video sharing, in which the mobile devices are connected to the cloud server for real-time interactive game videos, while sharing the received video frames with their peers via ad hoc network connections. This work is the first approach in cooperative sharing study for cloud gaming scenarios, which aims to substantially reduce the transmission rate from cloud server to the game clients, thus, to overcome the bottleneck of network access. It has investigated the video correlation patterns and provide a modeling for gaming and player interactions. As suggested by the experimental results, expected overall server transmission rate for multiplayer ARPG is reduced by up to 64% with optimal encoder and 54% with more practical one-hop restricted encoding solution.

However, the proposed framework still lacks consideration from the following aspects: *i) Mobility Issue:* the proposed system assumes an ideal case that the network bandwidth within

[1]http://www.onlive.com
[2]http://www.gaikai.com
[3]http://www.g-cluster.com

the ad hoc cloudlet is unlimited, which is unpractical in real scenarios: according to the nature of wireless communications, the video frame sharing among mobile devices are strictly constrained by their distances introduced by the mobility of terminals. *ii) Network Diversity Issue:* the previous work assumes all mobile devices has same quality network access to the cloud, however, the networking between terminals and cloud are subjected to the signal strength and environmental noises. In fact, The variety of network quality will strongly effect the overall system performance. *iii) Fairness Issue:* the proposed system only focus on the optimization of the system without considering fairness among players. In fact, no one wants to always sacrifice his/her bandwidth. The case is getting worse when players are using paid network: need to pay more if the player download more video frame from the cloud, while there is no incentive when they share to others in the ad hoc networks.

In this paper, we investigate a reputation-based multiplayer fairness for ad-hoc cloudlet-assisted cloud gaming system. The contribution of this work is summarized as follows:

- *System Formulation:* we study and formulate the the proposed cloud gaming system, focusing on the players' mobility and the network quality diversity of terminal devices' network .
- *Reputation based Fairness:* we propose a reputation-based multiplayer fairness scheme for the cloudlet-assisted cloud gaming system.
- *Numerical Evaluation:* we conduct preliminary simulations to evaluate the efficiency of proposed system in terms of fairness.

The reminder of the paper is as follows. We review related work in Section II. We then provide the system overview in Section III. We formulate the problem in Section IV and the proposed reputation-based fairness scheme is described in and V, respectively. Experiments on optimizing the overall latency and enabling partial offline execution are conducted in Section VI. Section VII concludes the paper.

II. Related Work

A. Correlations of videos frames

Inter frames, e.g. P-frame, is a frame in a video compression stream which is expressed in terms of one or more neighboring frames. Its size, which affects the system performance, is subject to the correlation of the encoded video frames. Light field [9] and multiview [10] video Streaming have conducted studies on this topic. Light field is a large set of spatially correlated images of the same static scene captured using a 2D array of closely spaced cameras. The correlations of light field images are studied and formulated in work [11], which indicated the correlation between two different views to a static scene is related to the geographical distances between each other. Interactive multiview video switching [12] designs a pre-encoded frame representation of a multiview sequence for a streaming server, so that streaming clients can periodically request desired views for successive video frames in time.

B. Real-time Video Encoding

Unlike light field and multiview switching, encoding for cloud gaming videos is essentially a real-time encoding process. The cloud encode video frames immediately after the game scenes are rendered. The fundamental idea of encoding is very simple: to starting with a intra-coded frame, e.g. I-frame, and then follows a certain number of inter frames, such as P-frame [13], distributed source coding (DSC) frames [14], etc. Therefore, how to determine the sequence of various types of frames becomes the most critical problems in video encoding, in order to achieve the tradeoff between bit rate and error rate. In recent video encoding research, the GOP (Group of Pictures) [15] length is set to be adaptive, which implies a structure with one I-frame and variable number of inter frames.

III. System Overview

The architectural framework of proposed cloudlet-assisted multiplayer cloud gaming system is illustrated in Fig. 1. Similar to the existing cloud gaming work, instances of **Game Engine** are hosted in the cloud to provide gaming services for players. They are connected to a **Multiplayer Game Server** in conventional fashion to facilitate interactions between avatars.

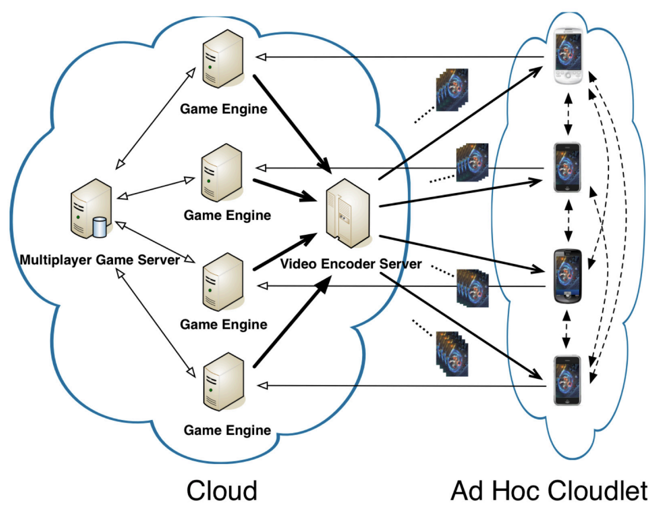


Fig. 1. Ad Hoc Cloudlet-Assisted Multiplayer Cloud Gaming System

The novelty of our proposed system is to introduce two additional components: **1) Video Encoder Server** is acting as a gateway, which explores the correlations between video frames for distinct players to perform centralized encoding, with the purpose of minimizing server transmission rate. In this work, we consider cloud as a infinite resource provider, therefore, the computational power of the encoder server is unlimited. **2) Ad Hoc Cloudlet** is a cooperative cloudlet constructed by participating mobile devices. They utilize a secondary network, e.g. WiFi ad hoc network, to share the video frames they received from the cloud server. We assume bandwidth for the ad hoc WLAN is sufficiently large for all mobile devices in the immediate neighborhood to share their frames when needed. Thus, the bandwidth constraint inside the cloudlet is not explicitly modeled.

IV. Problem Formulation

In this section, we mathematically model the ad-hoc cloudlet-assisted cloud gaming system, and formulate the reputation-based multiplayer fairness problem.

A. Avatar Behavior

We define the gaming map as a 2-Dimensional (2D) map with a size of $m \times m$ screens. On this particular map, we follow our previous work [8] to formulate the walking strategies of n players' avatars as *random walk* and *group chase* with probabilities p_{rw} and p_{gc} , respectively. For *random walk* movement, an avatar either holds it position with probability p_h or moves to its adjacent n_{adj} directions with identical possibilities p_c. To simplify the model, we set $p_h = p_c = \frac{p_{rw}}{n_{adj}+1}$. For *group chase* movement, an avatar will randomly select another avatar in the scene and move towards it for a certain period of time t_{chase}. Let the probability of group chase movement be $p_{gc} = 1-p_{rw}$, then the probabilities of any of the other $n-1$ target avatars to be chased will all equal $p_{appr} = \frac{p_{gc}}{n-1}$. Note that we set the moving unit for each avatar in a unit time to be k pixels, and denote w and h as the width and height of the gaming screen in pixels. Given that the system restricts the avatar to be in the center of the screen, all avatars' position coordinates will be restricted to (x, y), where $x \in [0, \frac{(m-1)w}{k}], y \in [0, \frac{(m-1)h}{k}]$.

B. Video Frame Correlation

Same as previous work, we formulate the frame sizes for two types of video frames: *Intra-video P-frame* and *Inter-video P-frame*. The *Intra-video P-frames* refer to the video frames that are encoded by predicting to their previous frames in the same video stream. An *Intra-video P-frame*'s size P_a is subjected to the variance of the game video content, which follows the following Poisson Distribution with $E(P_a) = \mu$:

$$f(P_a) = \frac{\mu^{P_a} e^{-\mu}}{P_a!} \tag{1}$$

The *Inter-video P-frames* refer to the video frames that are encoded by predicting to peer game videos' frames. An *Inter-video P-frame*'s size P_e is subjected to the correlation between two videos for corresponding peering game players, which is formulated as the following equation:

$$P_e(ij) = \begin{cases} [1 - \frac{(w-|\Delta x|)(h-|\Delta y|)}{wh}]I\rho, & |\Delta x| < w, |\Delta y| < h \\ I\rho, & otherwise \end{cases} \tag{2}$$

where I is the size of an intra frame, ρ is the compression ratio that the encoder is able to achieve, and $\Delta x = x_1 - x_2, \Delta y = y_1 - y_2$ provided that (x_1, y_1) and (x_2, y_2) denote the coordinates of the ith and jth player on the map.

With P_a and P_e, we define the video frame correlation matrix P. Thus, an element $P_{ij,i \neq j}$ stores the frame size of an *Inter-video P-frame* to decode ith player's video frame by predicting jth player's. In contrast, P_{kk} saves the frame size of an *Intra-video P-frame*, which enables the kth player to decode his/her current video by predicting the proceeding frame of his/her own video.

C. Terminal Mobility

To demonstrate the mobility of mobile devices, we set up an $r \times r$ m^2 gaming region. Each player is restricted in this gaming region with physical position represented as (X_i, Y_i), where $i = 1, 2, ..., n$ and $X_i \in [0, r], Y_i \in [0, r]$ are the X- and Y- coordinates of the ith player. In the gaming region, players randomly move within s meters in both X- and Y- directions in every 30 seconds, i.e. $\Delta X_i \in [-s, s], \Delta Y_i \in [-s, s]$ where ΔX_i and ΔY_i represent the movement of ith player in X- and Y- directions in every 30 seconds. The maximum inter-device communication distance, or the device communication range, is c meters.

Based on this model, we formulate the relationship between n players' terminals as an $n \times n$ matrix E. The numeric value of an element in matrix E is defined to be either 0 or 1, where $E_{ij} = 1$ represents that the ith player's terminal is within the communication range of jth player's terminal. The matrix E is derived by:

$$E_{ij} = \begin{cases} 1, & D_{ij} \leq c \\ 0, & otherwise \end{cases} \tag{3}$$

where

$$D_{ij} = \sqrt{(X_i - X_j)^2 + (Y_i - Y_j)^2} \tag{4}$$

is the distance between the ith player and the jth player.

D. Network Quality Diversity

In practical scenarios, the players' network conductivities are of various quality, according to the signal strength, environmental noises, reflection, scattering, diffraction, etc. Here we formulate the network quality diversity as a vector N with n elements, where N_i represents the network quality of the ith player. In order to simplify our model, we randomly select an integer $k \in [1, n]$ and assume $N_i = k/n$. Note that, in our proposed model, larger value indicates better network quality.

E. Video Encoding Solution

For the proposed system, to find out an optimal video encoding solution that fulfills the requirement is the most critical issue. In this paper, we formulate a video encoding solution as an $n \times n$ matrix M, where n represents the number of players. The numeric value of an element in matrix M is defined to be either 0 or 1, where $M_{ij} = 1$ represents that the ith player's video frame is decoded by predicting to jth player's. Apparently, an element $M_{kk} = 1$ represents that the kth player's terminal will download an *Intra-video P-frame* from the cloud, while $M_{ij} = 1, i \neq j$ represents that ith player's terminal is able to explore the correlations from jth player's decoded video frame, thus, its video frame is decoded by the combination of *Inter-video P-frame* downloaded from cloud and a decoded DSC video frame *DSC-frame* received from peer terminal via the ad hoc network.

To guarantee that the solution represented by a particular M can be adopted as a system encoding solution, a validation on the solution is required.

1) Information Integrality: In the distributed decoding system facilitated by the ad hoc cloudlet, it is obviously that at least one player needs to download *Intra-video P-frame* from the cloud, to provide future reference for its peers. Thus, at least one of the diagonal elements of M is 1, which is described as following equation:

$$tr(M) = \sum_{i=1}^{n} M_{ii} \geq 1 \tag{5}$$

2) Decoding Reliability: Moreover, all players' terminals requires either *Intra-video P-frame* or *Inter-video P-frame* to decode their video frame. Hence, the sum of elements in each row of M shall be equal to 1, as formulated by:

$$\forall i \in M_{ij}, \sum_{j=1}^{n} M_{ij} = 1 \tag{6}$$

3) Loop-Free: With above feature, a solution is still not guaranteed to be valid. A problem called *decoding loop* will result in invalid solutions to the system. To solve this problem, we consider non-zero elements in M as the decoding vectors for n players and further formulate these vectors to a graph $G = (N, E)$, where finite sets N and E contains the nodes and directed edges respectively. Some notations are defined in Table I for our ongoing analysis.

TABLE I. SOLUTION GRAPH NOTATIONS

Node	Each player is represented as either an *inter-node* γ_x or an *intra-node* λ_x. If a player will download images from the server via *intra-video P-frame*, the player is represented as an *intra-node*; otherwise, the player is represented as an *inter-node*. The set of all nodes $N = \{\gamma_1, \gamma_2, ..., \gamma_m, \lambda_1, \lambda_2, ..., \lambda_n\}$ contains m *inter-nodes* and n *intra-nodes*.
Edge	Each edge connects two nodes and has one direction. An edge pointing from γ_1 to γ_2 is represented as (γ_1, γ_2). If player 1 and player 2 are represented as *inter-nodes* γ_1 and γ_2 respectively, then (γ_1, γ_2) indicates that player 1 will download his/her images from player 2 via an *inter-video P-frame*.
Path	Finite sequence of edges connecting distinct nodes forms a path. For example, $P_x = (\gamma_1, \gamma_2, ..., \lambda_n)$ is a path with a starting point γ_1 and an end point λ_n. An isolated *intra-node* (no edge pointing in) is on a zero-path $P_y = (\lambda_n)$.
Loop	A path combined with an edge pointing from the end point of the path to the starting point of the path is called a loop. For $P_x = (\gamma_1, \gamma_2, ..., \gamma_n)$, $C_y = P_x + (\gamma_n, \gamma_1)$ is a loop with n nodes $\{\gamma_1, \gamma_2, ..., \gamma_n\}$.
Valid Path	A path ending at an *intra-node* is called a valid path. A zero-path is also a valid path.
Decoding Dependance	An *intra-node* decodes its image by default (by downloading directly from the server, which is not shown in our analysis.) An *inter-node* decodes its image only if it is on a valid path.
Valid System	If each node in the system can achieve its image, then this system is a valid system.

We here provide a statement that, if a graph G contains loop, its corresponding encoding solution M is not able to be decoded in the ad hoc cloudlet. Following is the proof:

Lemma 1. *No* intra-node *or valid path is on a loop.*

Proof: Since any *intra-node* does not point out, it must not be on a loop. For the same reason, since any valid path ends at an *intra-node* that is not on a loop, this path must not be on a loop. Theorem has been proven. ■

Theorem 1. *If a system is valid, then no loop is present in the system.*

Proof: Since the system is valid, each *inter-node* must be on a valid path. By Lemma 1, no *intra-node* or *inter-node* is on a loop, so no loop is present in the system. Theorem has been proven. ■

Theorem 2. *If no loop is present in a system, the system is valid.*

Proof: Suppose to the contrary that a system with no loop is not valid. Then, there exists an *inter-node* γ_x in the system such that by choosing γ_x to be the starting point, we can always find a longest path $P_x = (\gamma_x, \gamma_{x+1}, ..., \gamma_{x+n})$ with n edges. Since P_x is the longest path (i.e. γ_{x+n} cannot point to an $(n+2)th$ node) and *inter-node* γ_{x+n} has an edge pointing out, there must exist an edge $(\gamma_{x+n}, \gamma_{x+k})$ such that γ_{x+n} must point to γ_{x+k} where $k = 0, 1, 2, ..., n-1$. Then $(\gamma_{x+k}, \gamma_{x+k+1}, ..., \gamma_{x+n}) + (\gamma_{x+n}, \gamma_{x+k})$ forms a loop, which is contradictory to our assumption. Therefore, the theorem has been proven. ■

Therefore, a system is valid if and only if no loop is present in a system.

In order to provide a loop-free solution, M is mandatory to satisfy the following equation:

$$\forall p \in \{1, 2, ..., n\}, tr(M^p) = tr(M) \tag{7}$$

Hereby we provide proves for the statement as follows:

Proof: In the predefined solution $n \times n$ matrix M, we define: *i) Two-node loop:* $\exists\ i, j \in \{1, 2, ..., n\}$ *and* $i \neq j$, *s.t.* $m_{ij} \cdot m_{ji} = 1$, *ii) Three-node loop:* $\exists\ i, j, k \in \{1, 2, ..., n\}$ *and* $i \neq j, j \neq k, k \neq i$, *s.t.* $m_{ij} \cdot m_{jk} \cdot m_{ki} = 1$, *iii) Similarly for higher order loops*. Denote $Q = M^2$, such that,

$$q_{ij} = \sum_{h=1}^{n} m_{ih} \cdot m_{hj}$$

Note that, since $m_{ij} \in \{0, 1\}, m_{ij}^k = m_{ij}$ for $k = 1, 2, ..., n$, then we derive:

$$\begin{aligned} q_{ii} &= \sum_{h=1}^{n} m_{ih} \cdot m_{hi} = m_{ii}^2 + \sum_{\substack{h=1 \\ h \neq i}}^{n} m_{ih} \cdot m_{hi} \\ &= m_{ii} + \sum_{\substack{h=1 \\ h \neq i}}^{n} m_{ih} \cdot m_{hi} \end{aligned}$$

$$
\begin{aligned}
tr(Q) &= \sum_{i=1}^{n} q_{ii} = \sum_{i=1}^{n}(m_{ii} + \sum_{\substack{h=1\\h\neq i}}^{n} m_{ih}\cdot m_{hi}) \\
&= \sum_{i=1}^{n} m_{ii} + \sum_{i=1}^{n}(\sum_{\substack{h=1\\h\neq i}}^{n} m_{ih}\cdot m_{hi}) \\
&= tr(M) + \sum_{i=1}^{n}(\sum_{\substack{h=1\\h\neq i}}^{n} m_{ih}\cdot m_{hi})
\end{aligned}
$$

Since $m_{ij} \in \{0, 1\}$, if there is no *two-node loop*, then,

$$m_{ij}\cdot m_{ji} = 0, \forall i, j \in \{1, 2, ..., n\} \; and \; i \neq j$$

Thus, $\sum\limits_{i=1}^{n}(\sum\limits_{\substack{h=1\\h\neq i}}^{n} m_{ih}\cdot m_{hi}) = 0$, then $tr(Q) = tr(M^2) = tr(M)$.

Now, let $X = M^3 = Q\cdot M$, if there is no two-node loop, we derive:

$$
\begin{aligned}
x_{ii} &= \sum_{h=1}^{n} q_{ih}\cdot m_{hi} = m_{ii}\cdot q_{ii} + \sum_{\substack{h=1\\h\neq i}}^{n} q_{ih}\cdot m_{hi} \\
&= m_{ii}^3 + \sum_{\substack{h=1\\h\neq i}}^{n} q_{ih}\cdot m_{hi} = m_{ii} + \sum_{\substack{h=1\\h\neq i}}^{n} q_{ih}\cdot m_{hi} \\
&= m_{ii} + \sum_{\substack{h=1\\h\neq i}}^{n}(\sum_{\substack{v=1\\v\neq i,h}}^{n} m_{iv}\cdot m_{vh}\cdot m_{hi})
\end{aligned}
$$

Thus,

$$
\begin{aligned}
tr(X) &= \sum_{i=1}^{n} x_{ii} = \sum_{i=1}^{n}(m_{ii} + \sum_{\substack{h=1\\h\neq i}}^{n}\sum_{\substack{v=1\\v\neq i,h}}^{n} m_{iv}\cdot m_{vh}\cdot m_{hi}) \\
&= \sum_{i=1}^{n} m_{ii} + \sum_{i=1}^{n}\sum_{\substack{h=1\\h\neq i}}^{n}\sum_{\substack{v=1\\v\neq i,h}}^{n} m_{iv}\cdot m_{vh}\cdot m_{hi} \\
&= tr(M) + \sum_{i=1}^{n}\sum_{\substack{h=1\\h\neq i}}^{n}\sum_{\substack{v=1\\v\neq i,h}}^{n} m_{iv}\cdot m_{vh}\cdot m_{hi}
\end{aligned}
$$

Since $m_{ij} \in \{0, 1\}$, if there is no *three-node loop*, then,

$$m_{iv}\cdot m_{vh}\cdot m_{hi} = 0, \forall i, v, h \in \{1, 2, ..., n\}, i \neq v, v \neq h, h \neq i$$

thus, $\sum\limits_{i=1}^{n}\sum\limits_{\substack{h=1\\h\neq i}}^{n}\sum\limits_{\substack{v=1\\v\neq i,h}}^{n} m_{iv}\cdot m_{vh}\cdot m_{hi} = 0$, then $tr(X) = tr(M^3) = tr(M)$.

Using the same approach for higher order loops, we conclude that, to guarantee loop-free solution, the following equation shall be satisfied:

$$\forall p \in \{1, 2, ..., n\}, tr(M^p) = tr(M) \tag{8}$$

■

4) Mobility Constraints: The decoding procedure is constrained by the communication in ad hoc network, which is specifically constrained by the neighboring matrix E in our system definition. Hence, we hereby formulate the mobility constraints into the validation of solution M, as shown in following equation:

$$M = M \odot E \tag{9}$$

F. Optimization Target

As previous work [8] indicates, minimization in server transmission rate is of great importance to improve the system efficiency. However, transmission data size is not the only factor that impacts the system performance. Network quality is also a critical issue in effecting the players' quality of experience (QoE). For instance, with a specific transmission minimization matrix M, player i shall be the dependence of peering terminals, while it is struggling with poor network access, the decoding prediction of the whole ad hoc cloudlet system will be derated. According to this, we introduce a novel notation *communication cost*, which consider both the networking data size and the network quality. Hence, with video correlation matrix P and video encoding solution M, we can derive the overall communication cost θ by the following equation $\theta(M, P, N)$:

$$\theta(M, P, N) = \sum_{i=1}^{n}\sum_{j=1}^{n}(M_{ij}\cdot P_{ij})/N_i$$

Therefore, we derive the objective function O to represent the optimization target:

$$
\begin{aligned}
&\text{Minimize:} && O = \theta(M, P, N) \\
&\text{Subject to:} && (5)(6)(7)(9)(15)
\end{aligned}
$$

V. Reputation-based Fairness

Downloading *inter-video P-frame* to explore correlations from peer players' video is generally more advantageous than downloading those from the server via an *intra-video P-frame*, in terms of data transmission speed, power consumption, data expense and others. However, no one wants to always sacrifice his/her bandwidth. The case is getting worse when players are using paid network: need to pay more if the player download more video frame from the cloud, while there is no incentive when they share to others in the ad hoc networks.

An intuitive solution to achieve fairness is to set up new objective functions for system optimization. To illustrate the fairness among multiple players in the proposed ad hoc cloudlet-assisted cloud gaming system, we need to select an index value to summarize the variance of bandwidth usage for each player. We first derive a set of the network transmission rate $B = \{b_1, b_2, ..., b_n\}$ for all players as follows:

$$b_i = \sum_{j=1}^{n} M_{ij} P_{ij} \tag{10}$$

where b_i indicates the ith player's network bandwidth consumption and $i = 1, 2, ..., n$. Afterwards, we calculate the variance of $\sigma(B)$ as the index value of fairness:

$$\sigma(B) = \frac{1}{n} \sum_{b_i \in B} (b_i - \frac{1}{n} \sum_{b_i \in B} b_i)^2 \tag{11}$$

Therefore, the optimization target of achieving fairness for multiplayer can be summarized as the following equation:

$$\text{Minimize: } \sigma(B), \quad \text{Subject to: } (5)(6)(7)(9)(15)$$

If we consider the optimization in more general case that balances the tradeoff between bandwidth consumption and the fairness among multiplayer, we can instead formulate the optimization target $O(\lambda)$ as a corresponding unconstrained Lagrangian optimization for given Lagrange multiplier λ:

$$\begin{aligned} &\text{Minimize:} && O(\lambda) = \theta(M, P, N) + \lambda\sigma(B) \\ &\text{Subject to:} && (5)(6)(7)(9)(15) \end{aligned}$$

However, the above objective function is not a perfect solution to the fairness problem. There are still two critical issues remaining:

- *Inefficiency:* to optimize the fairness in each encoding procedure is an inefficiency approach. In fact, no better how the algorithm dedicate to provide average communication costs for all players, there shall be at least one player downloading intra-video P-frame from the cloud, in order to serve as the starting point of video sharing. Therefore, it is infeasible to be fair in every frame encoding.
- *Irrational:* to provide a fairness mechanism in each encoding procedure is not an intellectual decision. First, optimization in fairness will introduce negative influence to the communication cost, which results in system performance degradation; Second, players are always participating a gaming session in a period of time, their scarification in a particular time intervals can be compensated afterwards. Therefore, the fairness can be achieved in time manner balance multiple players in workload in time manner

According to these reasons, we introduce a reputation-based system to provide fairness to every player in terms of *intra-video* and *inter-vedio P-frame* allocation. This proposed system enforces that, only a player with higher reputation value is able to take advantage from peers, which refers to exploit correlations from another player via an *inter-video P-frame* transfer. Each player starts from a reputation balance of zero, and the balance changes according to the following table:

TABLE II. REPUTATION-BASED FAIRNESS

Activity	**Reputation Balance Change**
$M_{ii} = 1$	10% of the downloaded *intra-video P-frame* size (in KB), i.e. 10%*P_{ii} is awarded to the reputation balance of Player i
$M_{ij} = 1$	100% of the downloaded *inter-video P-frame* size (in KB), i.e. 100%*P_{ij} is awarded to the reputation balance of Player j
$M_{ij} = 1$	100% of the downloaded *inter-video P-frame* size (in KB), i.e. 100%*P_{ij} is taken off from the reputation balance of Player i

In this case, players with too low reputation value will not be able to enjoy the power of inter-user image processing, and will be encouraged to try to build his/her reputation up. As players try to be an *intra-node* to build up their reputation quickly, the system is positively fostered and fairness is guaranteed.

Hereby we formulate the reputation-based fairness algorithm as follows. Given an $n \times 1$ vector V whose ith entry represents the reputation value of the ith player, we derive $n \times n$ matrix U as:

$$U = [V, V, ..., V] \tag{12}$$

Thus, we formulate a reputation matrix R, in which each element R_{ij} represents the comparison result between reputation values of ith and jth player. The matrix R is derived by:

$$R_{ij} = \begin{cases} sign(U_{ij} - U_{ij}^T), & i \neq j \\ 1, & i = j \end{cases} \tag{13}$$

where

$$sign(u) = \begin{cases} 1, & u > 0 \\ 0, & u \leq 0 \end{cases} \tag{14}$$

such that we only allow a player with higher reputation value to download *inter-video P-frame* and process own images out with a *DSC-frame* from another player while allowing every player to download *intra-video P-frame* to potentially help others in order to build his/her reputation up.

Therefore, to achieve reputation-based fairness, we enforce the solution M to satisfy the following equation:

$$M = M \odot R \tag{15}$$

VI. SIMULATION

A. Experimental Setup

To validate the performance of our proposed system and encoding schemes, we set up the following experiments. For the video data, we download the images from Stanford bunny light field set[4], each image of size 1024×1024. To encode I- and P-frames, we used a H.236-based codec in [14]. Quantization parameters were set so that the Peak Signal-to-Noise(PSNR) of the encoded frames was around 32dB. As described in Section

[4]http://lightfield.stanford.edu/lfs.html

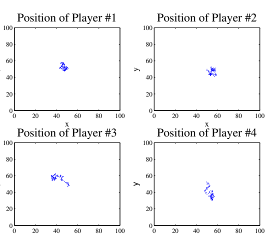
IV, we assume the P-frames for intra-video and inter-video follows designated distribution and formulation. Default values for parameters of the simulation is set in Table III.

TABLE III. DEFAULT SIMULATION PARAMETERS

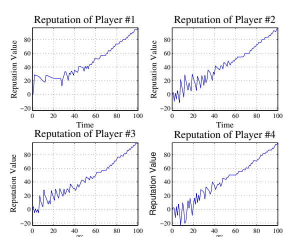
number of players n	8
simulation time T	500
fps (frame per second)	25
map Size $m \times m$	4
expectation of intra-video P-frame μ	28749 bytes
intra frame size I	245296 bytes
compression ratio ρ	0.7
screen width w	1024 pixels
screen height h	1024 pixels
unit step pixels k	32 pixels
random walk probability p_{rw}	0.6
chase time t_{chase}	3
adjunction direction n_{adj}	8
initial reputation value V_i	0

B. Effect of Mobility on Reputation Value

An important factor affecting the system is the distance between players. Players, in general, would not stay at the same position through out the gaming period. One might carry his/her gaming device to various places while gaming, e.g. to the fridge for a cup of cold drink, to the sofa for leisure, or even to the washroom. As players might move to different places while gaming, we assume that each player is random walking and will be able to move within 10 meters in both x- and y- directions in every minute. There is a limitation for inter-device communication such that *inter-video P-frame* sharing between two players might not be feasible. In our system, we set this maximum distance for *inter-video P-frame* sharing to be 20 meters.



(a) Mobility Trajectory of 4 players



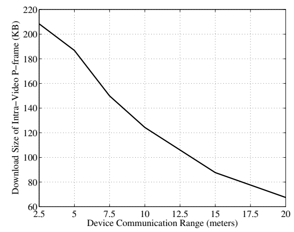
(b) Reputation Value of 4 players

Fig. 2. A Simulation Trace of 4 players within 100 units of time

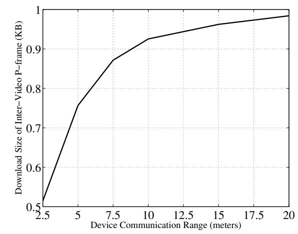
The combination of Fig. 2(a) and Fig. 2(b) illustrates how both restriction on reputation and restriction on distance work together. As we can see, once distance comes into play, less fluctuation is seen even if a player has reasonably high reputation value, indicating that the particular player is in a position that is too far from peering players, preventing him/her to exploit the correlations from other players with lower reputation values.

C. Effect of Inter-Device Connectivity on System Performance

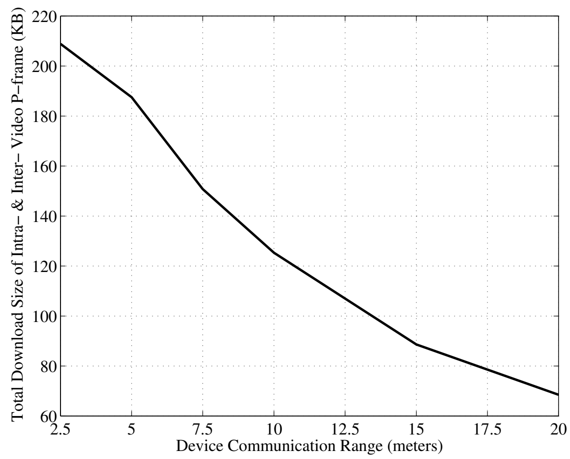
In this section, we study the impact of inter-device connectivity on the system performance. Given a variance of maximum communication range for terminal devices, we investigate the expected server transmission, from the perspectives of intra-video P-frame, inter-video P-frame and their sum.



(a) Intra-Video P-Frame



(b) Inter-Video P-Frame



(c) Total Download Size

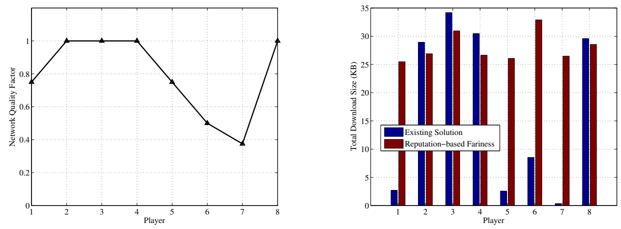
Fig. 3. Effect of Maximum Communication Range on Download Data Size

As depicted in Fig. 3(a) and Fig. 3(b), along with the increase of device communication range from 2.5 meters to 20 meters, the download of intra-video P-frame dramatically drops from 208 KB to 69 KB, while the inter-video P-frame downloading size climbs from 0.52 KB to 0.97 KB. Apparently, the changes on downlink rate on these two types of P-frames is introduced by the inter-player video cooperative sharing: the larger communication range the terminals have, the more probable they are able to exchange their video frames, thus, to exploit the correlations with inter-video P-frames. Since an inter-video P-frame can only be adopted when it is smaller than the concurrent intra-video P-frame, more inter-video P-frame downloading implies more bandwidth is saved from the system perspective. Hence, as the sum of these two figures, Fig. 3(c) shows a descending trend of total download size of intra- and inter- P-frames, which is inverse proportional to the communication range of terminals.

D. Fairness Achievement

In this section, We evaluate the efficiency of the propose reputation-based system in terms of fairness in data downloading size. Random seeds have been applied to iterative experiments that simulate a series of video encoding procedures.

Fig. 4 illustrates an encoding example in a snapshot of simulation. As shown in Fig. 4(a), the second, third, fourth



(a) Network Quality Factor Instance (b) Total Download Size Comparison

Fig. 4. A Snapshot of Simulation

and eighth players have high quality connectivity to the cloud server, while the seventh player are suffering from poor network condition. Accordingly in Fig. 4(b), with previous non-reputation-based solution, the seventh player shares the lowest downloading size among all peering players, since it always receive benefits from others without dedication. This phenomenon results in an unfair scenarios: the total server transmission rates for distinct players are unbalanced. In contrast, with the proposed reputation-based scheme, we can identify from the figure that, the bandwidth consumptions are more equilibrium among all devices. Note that, reputation-based solution obviously increase the total download size, as players with weak network qualities, e.g. seventh player, need to download more intra-video P-frames. However, this approach intrinsically exclude those unwelcome terminals from video sharing, which significantly improve most players' quality of experience.

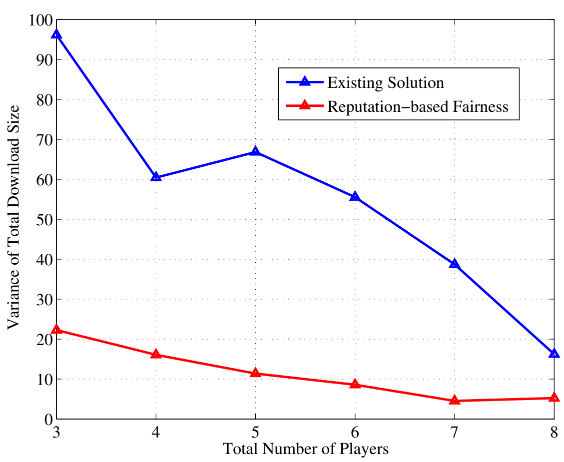


Fig. 5. Variance of Total Download Size Comparison

In order to compare the fairness of proposed reputation-based approach and existing solution, we use σ, the download size variance defined in Section IV, as an index. With a series of experiments, Fig. 5 depicts the simulation result that the reputation-based system outperforms previous scheme without fairness-aware, in terms of fairness.

VII. Conclusion

Cooperative video sharing with ad hoc cloudlet has been investigated as a bandwidth efficiency solution in cloud gaming systems. In this work, we reconsider the system model, from the aspects of terminal mobility and variety of network conditions. Based on formulations, we study the fairness problem in existing system that might affect the players' enthusiasm to participate, and proposed a novel reputation-based multiplayer fairness scheme to address this critical issue. Preliminary simulations have been conducted to demonstrate the efficiency of our proposal.

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