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RESEARCH ARTICLE

Gamified Participatory D2D Communication for Encouraging User Participation Toward Future Mobile Communication

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ABSTRACT Device-to-Device (D2D) communication is a promising solution in next generation cellular technologies to efficiently provide on-demand connectivity. Among existing D2D communication schemes, the outband approach that uses unlicensed spectrum can eliminate the spectrum interference with cellular links. Although the autonomous outband is a strong option because of its simple operation, it is a significant problem to appropriately encourage the participation of mobile users. To address this issue, this paper proposes a gamified participatory D2D (GP-D2D) communication where mobile users compete their gain that is obtained through providing network connectivity for other mobile users. The contribution of this work is to propose a novel approach of the autonomous outband D2D communication for efficiently encouraging the active participation of mobile users. The feasibility of the proposed gamified approach is confirmed with theoretical analysis and computer simulations. It is implied from the results that gamification is an effective approach for autonomous D2D communication by defining appropriate game-settings such as gain mechanisms.

INDEX TERMS Mobile communication, wireless communication, communication system, wireless networks.

I. INTRODUCTION

The amount of global mobile traffic has been significantly increasing in the recent past. This trend is expected to continue in the era of beyond 5G. Since the reachability of radio wave decreases in accordance with the use of higher frequency bands such as millimeter wave (mmWave) radio, it becomes difficult for mobile network operators to efficiently provide network connectivity with wide coverage. It has been an important research issue to efficiently and densely deploy small cells with low-cost. A promising option is the concept of moving small cells [1]–[3] to deal with the spatio-temporal fluctuations in the mobile traffic demand due to population movements [4]. Another option is Device-to-Device (D2D) communication [5].

D2D communication is intensely studied in recent years as a promising solution for providing on-demand wireless connectivity among devices [6], [7]. It enables direct communication between mobile devices to enhance mobile coverage without traversing a mobile base station (BS). The concept of mobile D2D communication is depicted in Fig. 1. When a user activates access point (AP) functions, e.g. Wi-Fi tethering on a smartphone, the user becomes a host to provide network connectivity to other mobile users. The neighboring users connect the host terminal as clients to access the Internet. Unlike fixed models composed of fixed Wi-Fi APs such as FON and OpenSpark, mobile D2D communication can dynamically enhance network connectivity if APs are appropriately activated.

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The approaches for D2D communication are classified into inband and outband as regards the employed spectrum. While the inband approach uses cellular spectrum, the outband uses unlicensed spectrum. The spectrum interference with cellular links is eliminated in the outband approach. The outband D2D schemes are further classified into controlled ones and autonomous ones. The spectrum resources are preallocated for users in the controlled D2D to ensure fair use of wireless resources. In the autonomous schemes, mobile devices are responsible for establishing D2D links. A significant advantage of the autonomous outband is the simple operation which is because mobile network operators do not have control over mobile devices. A mobile user activates AP functions of his/her user equipment (UE) such as a smartphone as a host to provide network connectivity for other devices which are called clients. An important problem for the autonomous approach is to appropriately encourage mobile users to provide connectivity to other devices. Some research works have tackled this issue by introducing incentive mechanisms to ensure the participation of mobile users [8]–[10], where users receive rewards for providing connectivity. Monetary and non-monetary rewards can be employed in such schemes. Another approach is to establish an auction-based free marketplace for mobile users to buy and sell mobile bandwidth for building sharing economy in mobile networks [11]. However, it is still an unsolved issue to encourage mobile users to actively participate in D2D communication.

To address this issue, this paper proposes a concept of gamified participatory D2D (GP-D2D) communication for encouraging the participation of mobile users. Gamification is defined as the application of game-design elements and principles in non-game contexts. It has been used in marketing and related purposes to improve user satisfaction and participation [12]. This paper defines the game of providing connectivity where mobile users compete their gain that is obtained through providing connectivity to other mobile users. The basic idea of the proposed scheme was reported in [13], while the detail was not provided. Thus, this is the first paper to introduce the comprehensive concept and numerical results of the proposed GP-D2D communication. Here we summarize the contributions of this paper. The major contributions are:

- To propose a novel gamified approach of the autonomous outband D2D communication for efficiently encouraging the active participation of mobile users.
- To clarify effective game settings for satisfying spatially distributed traffic demand from the results of theoretical models and intense computer simulations.

The rest of this paper is organized as follows. Section II describes related works on D2D communication. Section III introduces the proposed gamification-based approach. Section IV describes the results of theoretical analysis for the proposed scheme. The advantage of the gamified approach is verified with multi agent simulation in section V. The performance of composed networks is evaluated with traffic simulation in section VI. Section VII provides the conclusion.

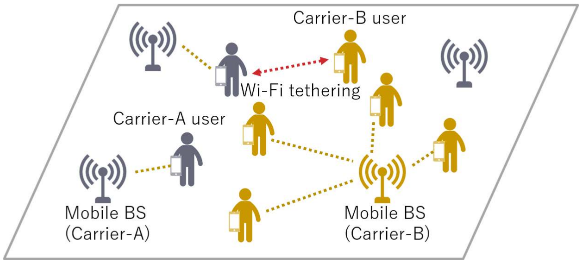


FIGURE 1. Concept of mobile D2D communication.

II. RELATED WORK

This section introduces related works. The concept of mobile D2D communication is also referred to as other names, e.g. user-provided connectivity (UPC), user-provided network (UPN), or crowdsourced mobile network. Crowdsourced wireless community networks which are composed of shared Wi-Fi APs were investigated in [14]–[16] to alleviate the limited coverage problem of Wi-Fi APs. UPN mechanisms have been investigated to utilize the power of wide-spread movable terminals [17]. A reimbursing scheme was proposed in [18] for enabling a mobile virtual network operator to offer free data quota as incentives. A cloud-controlled system was developed in [19] to dynamically apply forwarding policies. The interaction and conflict between mobile network operators and users were evaluated in [20], [21].

Many works on D2D have focused on the resource allocation problem among D2D links because it is one of the major challenges for autonomous outband D2D [6]. [22] proposed an adaptive cooperative network coding based MAC protocol. They analyzed the performance of cooperative outband D2D communication by exploiting idle devices as relay nodes. [23] developed a D2D opportunistic relay with quality of service (QoS) enforcement framework. The purpose of this relaying scheme was to handle channel opportunities offered by outband D2D relay nodes. [24] proposed an Age of Information based host-selection algorithm for D2D. The proposed algorithm improved the link stability among moving devices by considering the dynamics of received signal power. [25] investigated the problem of autonomous operation of device pairs in a heterogeneous cellular network with multiple BSs. They formulated the spectrum usage problem as a stochastic non-cooperative game. In this game, each player is defined as a learning agent. They developed a multi-agent Q-learning algorithm which converges to a mixed-strategy Nash equilibrium. The authors of [26] studied sub-channel assignment among remote radio head users and multiple D2D pairs using different bandwidth. The channel assignment problem was formulated as a mixed integer nonlinear programming problem. Then, this problem was re-formulated into a many-to-one matching sub-game. To minimize interferences and optimize the network performance, [27] proposed a distributed resource allocation algorithm for D2D based on matching theory. It was shown with computer simulations that this algorithm converged to a stable matching within finite iterations. [28] proposed a joint resource allocation and power control with deep reinforcement learning. In [29], a distributed antenna beamwidth optimization algorithm was developed based on multi-agent deep reinforcement learning. They modeled D2D links as agents that interact with the communication environment to refine their antenna beamwidth policies. Note that [30] pointed machine learning approach may not be optimum for resource management in D2D communications. [31] investigated socially-driven D2D communications where social ties are expected to boost D2D connection. This paper only provided conceptual analysis so that further research is required on a socially-driven approach.

It is another critical issue on autonomous D2D communication to ensure security. This is because there is no third party that is involved in verifying the authenticity of the devices. [32] proposed a lightweight/secure mutual authentication and key agreement protocol for Wi-Fi Direct. This protocol is based on a commit/open pair and well-known Diffie Hellman key exchange algorithm. For ensuring both peer-to-peer and group security in D2D, a versatile key management protocol for the Internet of Things was introduced in [33]. The proposed protocol can be used for both types of communications while providing a good level of resilience. For 5G-enabled vehicular ad hoc networks (VANETs), a hybrid D2D message authentication scheme was developed [34] for mutual authentication in a vehicle to vehicle (V2V) communication. The proposed group signature-based algorithm with a pre-computed lookup table reduced the computation overhead. Also, a lightweight near-field device authentication scheme in D2D was developed in [35] using a speaker and a microphone.

Cache-enabled D2D (C-D2D) is investigated in [36] to allow user devices to share their cached content with other user devices. They modeled interaction among users as a multi-person bargaining game considering heterogeneous content interest profile (CIP) and storage capacity to encourage cooperation among users. While this is an interesting approach, the mechanism design is optimized for C-D2D where caching in limited storage capacity is a major constraint. [37] investigated cooperative D2D-aided fog computing while reducing interferences and noises with a coalition game theory. Although there have been many research efforts on autonomous D2D communication, the efficient encouragement of user participation is still an unsolved issue. While the above works aim for autonomous D2D mechanisms, the goals are different; efficient caching of contents and fog computing integration. In this paper we propose a novel gamification-based approach that contributes for establishing on-demand mobile networks by efficiently encouraging mobile users to participate in the autonomous outband D2D communication. The goal of our work is to propose a novel gamification-based approach which is expected to provide not only efficiency but implicit merits such as the fun of competitive games. It can be noted that mobile D2D communication with the proposed idea can enhance crowd-sensing scenarios such as [38], [39] because the obtained data are dynamically relayed among participating user devices.

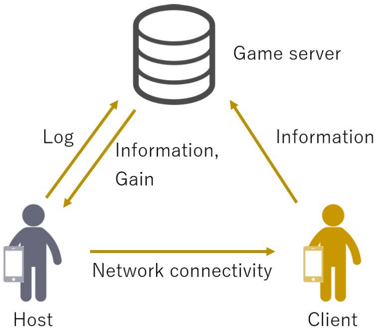


FIGURE 2. Concept of GP-D2D communication.

III. PROPOSED GP-D2D COMMUNICATION

A. CONCEPT AND SEQUENCE

Fig. 2 depicts the concept of the proposed GP-D2D communication. A game server is installed to manage the game. The hosts and clients are defined as the participants of the game. The clients periodically upload their information, such as locations, to the game server. The game server summarizes the uploaded client information. Hosts act based on the information received from the game server to obtain gain by providing connectivity to neighboring clients. The gain is computed by the game server with the uploaded connection log. The participated hosts compete for their gain. A host who obtained the maximum gain during a game period becomes the winner in the game. The clients acquire network access by participating in the game. The proposed approach leverages mobile D2D communication by appropriately setting the game statuses such as gain models and provided information.

The processing sequence of the proposed GP-D2D communication is depicted in Fig. 3. A game period consists of multiple time periods. The basic sequence is cyclically repeated in each time period. At the beginning of a time period, clients report their locations and approximate required data rates to the game server. The game server updates the targets and sends the target locations and required data rates to the hosts. Hosts act based on the received target information to maximize their own gain by providing network connectivity. Then, they report the connection log to the game server at the end of the time period. After certain time periods, the total gain is computed for each host to determine the winner.

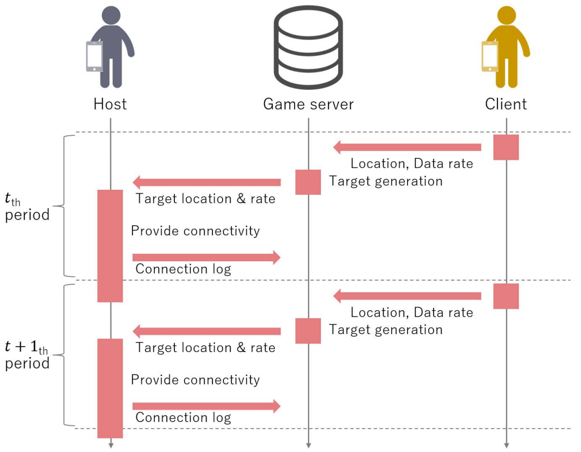


FIGURE 3. Sequence of GP-D2D communication.

TABLE 1. Variables.

Variable	Definition
t	Time period, $0 \leq t \leq T$
$\mathbf{C}(t)$	Set of clients at t
c	Client identifier
$d_c(t)$	Required data rate
$s_c(t)$	Actual data rate
$S(t)$	Demand satisfaction
R	Total demand satisfaction
$\mathbf{J}(t)$	Set of targets at t
j	Target identifier
$u_j(t)$	Assigned clients
$e_j(t)$	Assigned data rate
$\mathbf{Y}(t)$	Allocation state at t
L	Distance limitation
D	Capacity limitation
h	Host identifier
w_h	Weight of host
$g_h(t)$	Obtained gain at t
G_h	Total gain
$p_{h,j,t}$	Connection state

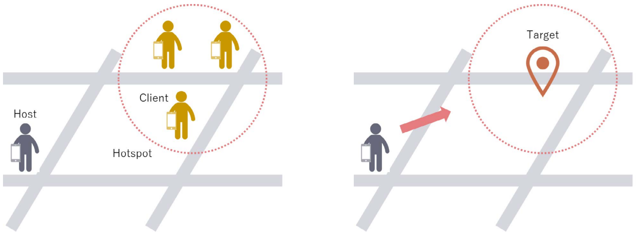
B. GAME SETTING

1) VARIABLE DEFINITION

The variables used in the proposed scheme are summarized in Table 1. The detail of each variable is introduced in the following description.

2) ASSUMPTION

The goal of this paper is to obtain the insight for better game-settings. The basic assumption is that hosts act for their own gain, not for the network coverage. That is, the spatio-temporal distribution of activated APs depends on the game-setting. Assume that a game where hosts seek targets which are presented on the map of their smartphones (like Pokémon GO). The target locations reflect the distribution of clients as shown in Fig. 4. The game server computes the target locations based on the information received from clients, i.e. the private information of clients is concealed from hosts. The detailed description on the target-generation is provided in the following section.



(a) Client distribution (b) Target information provided to host

FIGURE 4. Relationship between client distribution and target for host.

3) OBJECTIVE FUNCTION

Here we define the overall objective of the GP-D2D communication; it is reasonable that the objective of the game master is achieved by managing games. The objective function is defined to maximize the network coverage. As described above, the approximate required data rate of clients and their locations are reported to the game server in real-time. It is obvious that the reported demand should be satisfied by host users; a game-setting that can better satisfy the demand is defined as the better game in this paper.

Let $\mathbf{C}(t)$ denote the set of clients, and c denote their identifier. The required data rate of cth client at time t is defined as $d_c(t) > 0$. $t = 0$ and $t = T$ then denote the beginning and ending time of a game period, respectively. The actual data rate of cth client at t achieved by connecting with a host is described as $s_c(t)$. The demand satisfaction at t is formulated with these variables as

$$S(t) = \frac{\sum_{c \in \mathbf{C}(t)} s_c(t)}{\sum_{c \in \mathbf{C}(t)} d_c(t)}. \tag{1}$$

Thus, the objective function is described as the total demand satisfaction during a game period, which is formulated as

$$\mathbf{S} = \sum_{t=0}^{T} S(t) = \sum_{t=0}^{T} \frac{\sum_{c \in \mathbf{C}(t)} s_c(t)}{\sum_{c \in \mathbf{C}(t)} d_c(t)}. \tag{2}$$

C. TARGET GENERATION

As stated above, targets are generated to conceal the information of clients from hosts. Targets are updated at the beginning of each time period. The set of targets at t is described as $\mathbf{J}(t)$, and j is the identifier for them. Let $\mathbf{Q}(t) = \{q_{0,0,t}, \ldots, q_{c,j,t}, \ldots\}$ denote the set of allocation states where $q_{c,j,t}$ is the allocation state of cth client to jth target at t: $q_{c,j,t} = 1$ represents that cth client is allocated to jth target, and $q_{c,j,t} = 0$ otherwise.

The target generation algorithm is summarized in Algorithm 1. The following description is the step-by-step explanation of this algorithm. The goal of the algorithm is to compute the set of targets $\mathbf{J}(t)$ and allocation states of clients

$\mathbf{Y}(t)$ from the information of clients which is described as $\mathbf{C}(t)$. After the initialization (Line 1), an unallocated client i is selected (Line 3). Let L denote the distance limitation between a target and a client and D denote the capacity limitation of a target. The total data rate of clients assigned to jth target is described as $e_j(t)$. The number of assigned clients is defined as $u_j(t)$. If there is a target z that satisfies the distance and capacity requirement (Line 6), zth target is selected. Otherwise, a new target is generated near ith client (Line 11). Then, ith client is allocated to the target as $q_{i,z,t} = 1$ (Line 14). By repeating this procedure, the unallocated clients are allocated to targets so that the set of targets is updated.

Algorithm 1 Target Generation Algorithm

```
Require: $\mathbf{C}(t)$
Ensure: $\mathbf{J}(t), \mathbf{Y}(t)$
 1: $q_{c,j,t} \leftarrow 0 \forall c, j$
 2: while $\sum_{j \in \mathbf{J}} q_{c,j,t} = 0 \quad \exists c$ do
 3:     $i \leftarrow c \in \mathbf{C} \quad s.t. \sum_{j \in \mathbf{J}} q_{c,j,t} = 0$
 4:     $z \leftarrow null$
 5:     for all $j \in \mathbf{J}$ do
 6:         if $GetDistance(i, j) \leq L$ and $e_j(t) + d_i(t) \leq D$ then
 7:             $z \leftarrow j$
 8:         end if
 9:     end for
10:     if $z = null$ then
11:         $z \leftarrow GenerateNewTargetNear(i)$
12:         $AddTargetTo(\mathbf{J})$
13:     end if
14:     $q_{i,z,t} \leftarrow 1$
15:     $u_z += 1$
16:     $e_z += d_i(t)$
17: end while
```

The computational complexity of the target generation algorithm is determined by N_J which denotes the maximum number of targets. This is because the size of set $\mathbf{Q}(t)$ is determined as

$$|\mathbf{Q}(t)| = |N_J| \times |\mathbf{C}(t)|.$$

In the worst case, the computational complexity is approximated as $O(|N_J|^2)$.

D. GAIN MODEL

Let h denote the identifier for hosts. The capacity of a host as an AP is described as a weight w_h. The weight becomes large when the host employs a powerful terminal and/or better access to mobile networks. We define $g_h(t)$ as the gain obtained by hth host at t. From the definition, the total gain obtained during the game period is calculated as

$$G_h = \sum_{t=0}^{T} g_h(t). \tag{3}$$

Each host acts for maximizing the obtained gain G_h. Note that hosts do not consider the objective function of the game itself. $p_{h,j,t}$ is a binary variable that represents the connection state between hth host and jth target; if $p_{h,j,t} = 1$ is satisfied hth host is connected to jth target, and $p_{h,j,t} = 0$ otherwise.

In this paper we propose two gain models. There can be options for gain models to be employed considering the purpose of D2D communication in the deployed area. Each of the proposed model is explained in the following.

1) MODEL 1: RATE BASED

In this model, the obtained gain of hth host at t is formulated with $p_{h,j,t}$ as

$$g_h(t) = \sum_{j \in \mathbf{J}(t)} p_{h,j,t} w_h e_j(t), \tag{4}$$

which represents the total of requested data rate of targets connected to hth host. It is expected for this model to maximize the total of system throughput.

2) MODEL 2: TARGET SIZE BASED

In the second model, $g_h(t)$ is computed on the basis of the size of connected target, i.e. the number of connected clients. The obtained gain is simply formulated as

$$g_h(t) = \sum_{j \in \mathbf{J}(t)} p_{h,j,t} w_h u_j(t). \tag{5}$$

It is expected for this model to maximize the number of connected client devices.

IV. THEORETICAL ANALYSIS

This section describes the results of theoretical analysis for the proposed GP-D2D communication.

A. SIGNAL STRENGTH MODEL

Let us assume a simple model where a host seeks for a target on $x-y$ plane for simplicity. The host starts to obtain the gain when he/she arrives at the target. Since the target location is updated at the beginning of each time period, it is assumed that the host immediately follows the movement of the target. The distance between the host and the clients included in the target is defined as $\delta_c(t) \leq L$.

Let $r_{h,c}(t)$ denote the signal power from the hth host received at the cth client at t. The signal reception power is inversely proportional to the transmission distance based on the Friis transmission equation, and thus it is formulated as

$$r_{h,c}(t) = \frac{A}{\delta_c(t)^{3.5}} \geq \frac{A}{L^{3.5}}, \tag{6}$$

where A denotes a constant value assuming the signal propagation speed is far faster than the speed of nodes. The constant A is defined as

$$A = P_t G_a^{tx} G_a^{rx} \alpha \left(\frac{v}{4\pi f}\right)^2, \tag{7}$$

where P_t, G_a, v, α, and f denote the transmission power, antenna gain for transmitter/receiver, velocity of light, the adjustment coefficient, and carrier frequency.

B. TARGET TYPE

To clarify the difference of host behaviors derived from the game setting, let us assume two types of targets; a large-grained target and a small-grained target.

1) CASE 1: LARGE-GRAINED TARGET

First, assume that the target consists of small number of heavy users who are using high-rate applications such as video streaming. The obtained gain of the host for this target is formulated as

$$g_{h,LG}(t) = \begin{cases} w_h e_{LG}(t) & (Model1) \\ w_h u_{LG}(t), & (Model2) \end{cases} \tag{8}$$

where $e_{LG}(t)$ and $u_{LG}(t)$ denote the data rate and number of clients in the large-grained target.

2) CASE 2: SMALL-GRAINED TARGET

Second, let us assume that the target consists of large number of low-rate users such as text messaging. The obtained gain of the host is

$$g_{h,SG}(t) = \begin{cases} w_h e_{SG}(t) & (Model1) \\ w_h u_{SG}(t), & (Model2) \end{cases} \tag{9}$$

where $e_{SG}(t)$ and $u_{SG}(t)$ denote the data rate and number of clients in the small-grained target. Note that the host can connect the clients with sufficient signal reception power in both cases.

3) TARGET SELECTION

Consider there are two targets; one is a large-grained target and the other is a small-grained one. From the definition, we can simply assume $e_{LG} > e_{SG}$ and $u_{LG} < u_{SG}$ are satisfied. If we employ the model 1, the host seeks for the large-grained target because $g_{h,LG}(t) > g_{h,SG}(t)$ holds. On the other hand, if the model 2 is employed, the host seeks for the small-grained target because $g_{h,LG}(t) < g_{h,SG}(t)$ is satisfied. The host only acts for maximizing the gain, and thus the host behavior largely depends on the employed gain model. It is also obvious that the demand satisfaction is determined by the gain model, and thus there are suitable conditions for each gain model. In other words, the game setting should be determined based on the policy for enhancing network connectivity. The data rates for D2D communication links are also determined by the parameter settings such as the distance limitation L and the capacity limitation D.

C. NUMERICAL EXAMPLE

1) CONDITION

Here we introduce a simple numerical example. The variables in (7) are set as $P_t = 15$ dBm, $G_a^{tx} = G_a^{rx} = 0$ dBi, $\alpha = 100$, and $f = 5.6$ GHz. With these values, A in (7) is calculated as $A = 5.75 \times 10^{-5}$. The relation between the achievable wireless link rate and the signal reception power is summarized in Table 2, which assumes 40 MHz transmission bandwidth. Note that the shadow fading is not considered for the simplicity of the formulation. From Table 2, L is set as $\left(\frac{A}{r}\right)^{\frac{1}{3.5}} = 80$ meters to ensure $P_r \geq -79$ dBm. Let us assume the average of $\delta_c(t)$ is equal to $\frac{L}{2} = 40$ meters for simplicity, and thus the expected signal reception power is computed as $r = -68$ dBm.

TABLE 2. Transmission rate.

Reception power [dBm]	Transmission rate [Mbps]
$P_r < -79$	0
$-79 \leq P_r < -76$	30
$-76 \leq P_r < -74$	60
$-74 \leq P_r < -71$	90
$-71 \leq P_r < -67$	120
$-67 \leq P_r < -63$	180
$-63 \leq P_r < -62$	240
$-62 \leq P_r < -61$	270
$-61 \leq P_r < -56$	300
$-56 \leq P_r < -54$	360
$-54 \leq P_r$	400

2) TARGET SELECTION

a: CASE 1: LARGE-GRAINED TARGET

The parameters for a large-grained target is set as $e_j(t) = 10$ Mbps, $u_j(t) = 2$, and $w_h = 1$. The obtained gain of the host is

$$g_{h,LG}(t) = \begin{cases} 10 & (Model1) \\ 2. & (Model2) \end{cases} \tag{10}$$

b: CASE 2: SMALL-GRAINED TARGET

The parameters for a small-grained target is set as $e_j(t) = 2$ Mbps, $u_j(t) = 10$, and $w_h = 1$. The obtained gain is

$$g_{h,SG}(t) = \begin{cases} 2 & (Model1) \\ 10. & (Model2) \end{cases} \tag{11}$$

c: HOST BEHAVIORS

From (10) and (11), it was confirmed that $g_{h,LG}(t) > g_{h,SG}(t)$ holds with the model 1. Also, it was confirmed that $g_{h,LG}(t) < g_{h,SG}(t)$ is satisfied with the model 2. That is, the host seeks for large-grained targets with the model 1, while they seek for small-grained ones with the model 2 for maximizing the obtained gain as formulated above.

V. MULTI AGENT SIMULATION

The proposed gamified approach was evaluated via computer simulations. We used Mesa, which is an Apache2 licensed agent-based modeling framework in Python. The hardware environment was Dell Precision 7920 Tower with Intel Xeon

TABLE 3. **Application types.**

Type	Range of demand
High-rate	$10-20$
Medium-rate	$5-20$
Low-rate	$0-5$

Gold 6136 CPU and 64 GB memory. The simulation code is availabe at [40].

A. SIMULATION SETUP

The simulation conditions are provided in the following. The study area was set as a 200×200 meters square area, which is simulated as 20×20 grids. The time step in the simulation was defined as one minute and the game period was 100 minutes ($0 \leq t \leq 100 = T$). There were 500 clients in the simulated area. At each time period, they randomly moved to one of the surrounding 9 grids including the center cell itself at 10% possibility. For simulation simplicity, a target was generated at the center of each grid as long as any client was currently within the grid.

We assumed three types of applications for the clients including high-rate, medium-rate, and low-rate as summarized in Table 3. The demand at each time period was randomly determined in the defined range of demand. The clients randomly changed the application type by 10% possibility at each time period. The initial positions and application types of the clients were randomly determined.

There were 25 hosts in the simulated area. Their initial positions were also randomly set. At each time period, each host searched for the cell that provides the maximum gain from the surrounding 9 grids including the current position, and moved to the point. The maximum demand that a host can satisfy was set as 50. It was assumed that a host could catch the target located at his/her current cell.

The proposed approach was compared with a non-gamified approach where the gain was randomly determined, which is called the random model. The random model simulates a normal usecase where the positions of hosts are unpredictable. The simulations were iterated for 50 times for each condition.

B. SIMULATION RESULTS

The simulation results are described here. Fig. 5 shows the example distribution of hosts, clients, and demands with each model. Figs. 5a, 5b, and 5c show the results with the model 1, model 2, and non-gamified approach, respectively. Each figure consists of three sub-figures, namely a client distribution, a demand distribution, and a host distribution at $t = 100$. The client distributions are randomly determined by randomwalk of clients which is independent of the game settings. The demand distributions are also randomly generated based on the client distributions. The host distributions are determined by the game settings. With the proposed approach, more targets are caught by the hosts than the non-gamified scheme. That is, hosts seek for high-demand areas. Without the gamified approach, the hosts are uniformly distributed. This is because the hosts actively provide network connectivity for clients to obtain gain in return. The hosts with the model 1 efficiently provide connectivity to the clients in high-demand grids, i.e. hotspots. It is also shown that the hosts reached the grids with more number of users with the model 2.

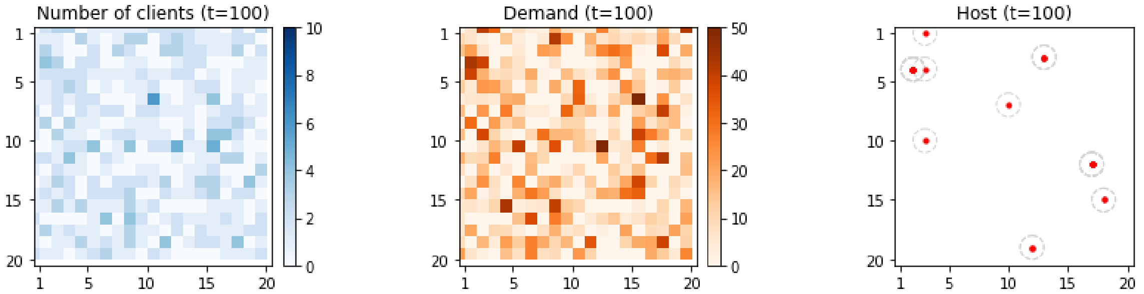
Fig. 6 summarizes the simulation results. The objective function defined in (2), the average demand satisfaction, and the average number of connected clients during each time period are shown. Each point represents each iteration with different seeds. Fig. 6a shows the objective function with each model. Fig. 6b is the average demand satisfaction during the game period. Fig. 6c is the average number of connected clients during the game period. The model 1 outperforms other approaches, because the high-rate streams are precedently connected by the hosts. Also, while the gain model 1 improves the demand satisfaction, the gain model 2 outperforms in terms of maximizing the number of connected clients. This results from the definitions of the gain in (4) and (5); the hosts only act for maximizing their own gain. The proposed gamified approach improves the demand satisfaction and the number of connected users compared with random approach. These simulation results indicate that the proposed gamified approach can encourage D2D communication; the game-setting can determine the maximized metrics. The employed gain model can be selected considering the policy of the D2D communication.

C. DISCUSSION

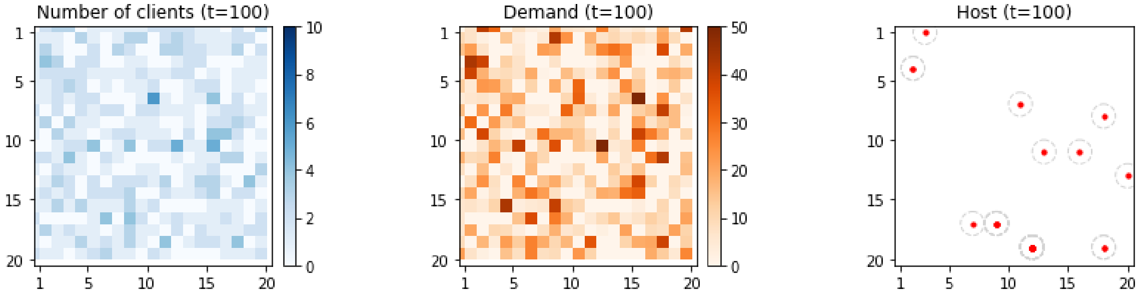
As described above, the proposed approach can efficiently encourage mobile users to provide network connectivity to other clients. While hosts only act for maximizing their own gain, the mobile networks are enhanced by the activated APs. The rewards for the winner of a game, i.e. the host who obtained the maximum gain in the game, can be monetary or non-monetary ones as investigated in the previous works. Also, it can be an incentive to have fun in competing with other participants for the rewards, which is a general characteristic of a gamification based approach. Since this paper presented the initial results of the gamified participatory D2D communication, it is a unsolved issue to establish more sophisticated game settings such as spatio-temporally dynamic gain models and user interfaces.

The target generation process in the proposed algorithm is effective for concealing the client information from hosts. As shown in Fig. 4, a target is generated from neighboring clients. A host only knows the target without any information of clients including their locations. The target location on the map is randomly determined so that clients' location information is hidden even when only one client is included in the target.

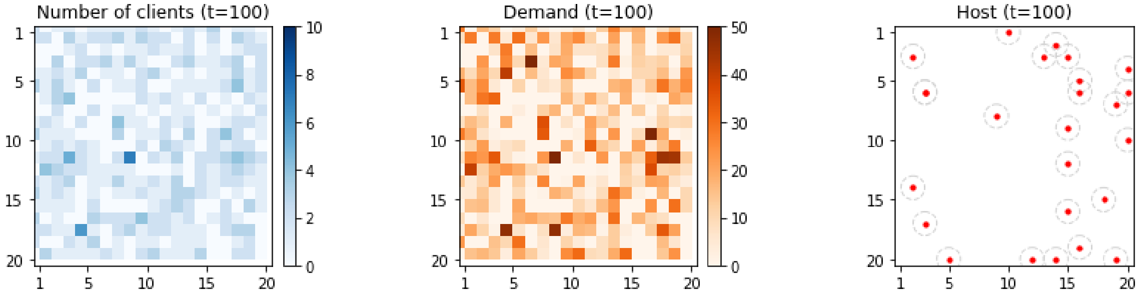
From perspective of implementation, it is a significant issue to motivate mobile users to participate in the game. This is because many hosts and clients are required to establish the game and to efficiently provide connectivity to mobile



(a) Distribution at $t = 100$ with Model 1



(b) Distribution at $t = 100$ with Model 2



(c) Distribution at $t = 100$ with Non-gamified model

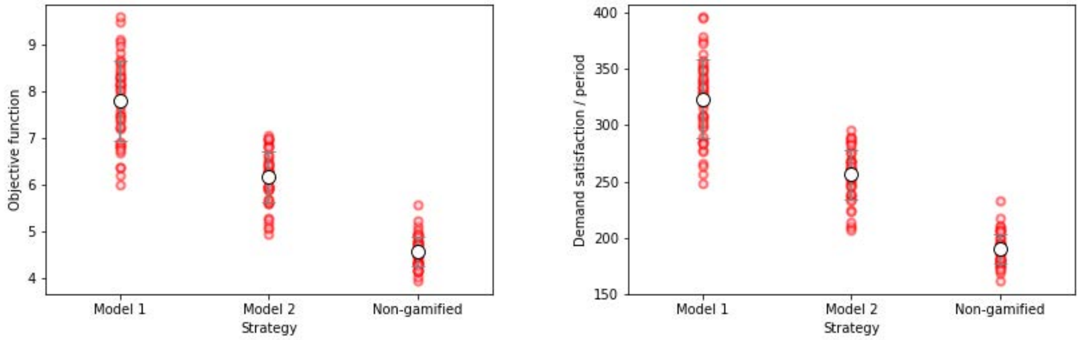
FIGURE 5. **Final distribution of hosts and clients.**

users. If user density is too sparse in a certain area, there are no hosts or clients to connect. Since mobile users have their own daily works, incentive setting, playability, and user interface of the mobile application are very important to ensure participation.

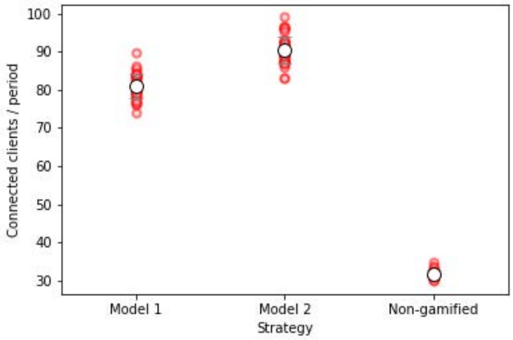
VI. WIRELESS NETWORK SIMULATION

A. SIMULATION CONDITION

On the basis of results of the multi agent simulation, throughput performance of the proposed approach is examined through a system level simulation. Consider the smartphone based D2D scenario, wide spread Wi-Fi, i.e. IEEE 802.11n wireless LAN is assumed as an access protocol which employs the carrier sense multiple access with collision avoidance (CSMA/CA). Table 4 lists conditions in the wireless network simulation. Since the finite buffer model is employed, the packet origination of each client is assumed to follow the Poisson distribution. Each client is assumed to set the random backoff before the packet transmission independently. The transmission rate is determined by the reception power of each client. The payload lengths are set to 1500, 500, and 150 Bytes to represent various kinds of application traffic and correspond to types defined in Table 3. The minimum contention window is identic for all users and is set to 15 time slots. Transmission failure is caused by only packet collision that the host receives multiple packets within a same duration. When packet error occurs, the relevant clients attempt to retransmit the same packets after the random backoff periods which are determined by exponentially increased contention window. The simulation area is 200 meters square wherein hosts and clients are distributed according to the prescribed gamified models. With the non-gamified one, they are uniformly distributed. The numbers of hosts and clients, and their migration model are the same as the multi agent simulation in Section V. We assume a large open space which includes indoor and outdoor; TGn Channel model C [41] is employed as the propagation model. The path loss, $L(\delta)$, which is the function of the distance between the



(a) Objective function (b) Avg. demand satisfaction



(c) Avg. connected clients

FIGURE 6. **Summary of simulation results.**

host and the client, δ, is given by

$$L(\delta) = \begin{cases} 20\log_{10}\left(\frac{4\pi\delta f}{v}\right), & \delta \le \delta_B \\ 20\log_{10}\left(\frac{4\pi\delta_B f}{v}\right) + 35\log_{10}\frac{\delta}{\delta_B}, & \delta > \delta_B \end{cases} \tag{12}$$

where δ_B denotes the breakpoint distance. The minimum carrier sense level is set to −82 dBm.

TABLE 4. **Simulation parameters.**

Preamble length of physical layer	28 μsec
Header length of MAC layer	30 Bytes
ACK length	14 Bytes
DIFS length	34 μsec
SIFS length	16 μsec
Slot time length	9 μsec
Minimum contention window	15 slots
Number of clients	500
Number of host	25
Transmission power	0 dBm
Carrier frequency, f	5.6 GHz
Propagation model	TGn channel model C
Breakpoint distance, δ_B	5 m
Shadowing deviation	3 dB ($\delta \le \delta_B$) 5 dB ($\delta > \delta_B$)
Minimum carrier sense level	−82 dBm

B. SIMULATION RESULTS

Fig. 7 shows the system throughput performance as the function of the input load. The input load denotes the sum of the offered load originated from clients connecting to the host, determined according to the aforementioned gain models. For comparison, simulation results of Model 1/ Model 2/Non-gamified are presented. When the input load exceeds a specific amount, the system throughput of each result becomes saturated. The proposed approach with the model 1 and the model 2 can improve saturated system throughput by 2.1 and 1.7 times compared with the Non-gamified one. Performance tendencies totally agree with the multi-agent simulation results. The rate-based gain model exhibits the best system throughput performance because the host preferentially supports closer clients. Connection-based metrics also contribute to throughput improvements. Although system throughput is expected to increase as the number of connected clients increases, it also tends to saturate due to the multiple access overhead.

Fig. 8 presents the time-varying characteristics of the system throughput and the number of connected clients, respectively. The average input load of each client was set to 7 Mbps. Here, all cases employ the same random seed at each moment and hence the performance differences among the approaches

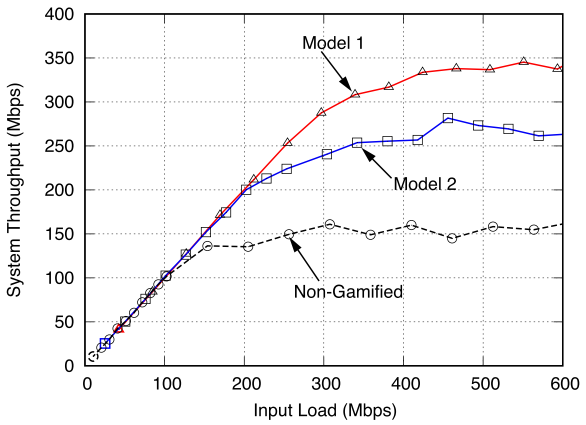
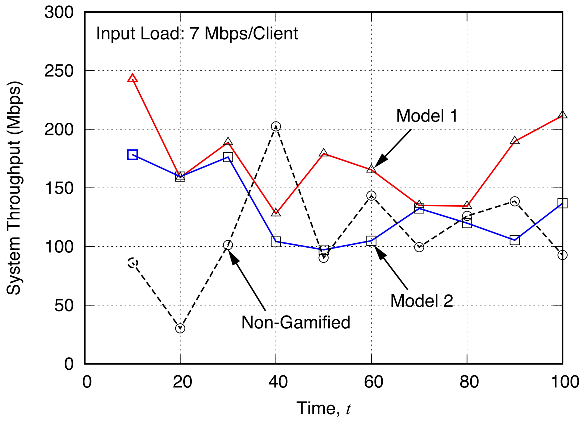
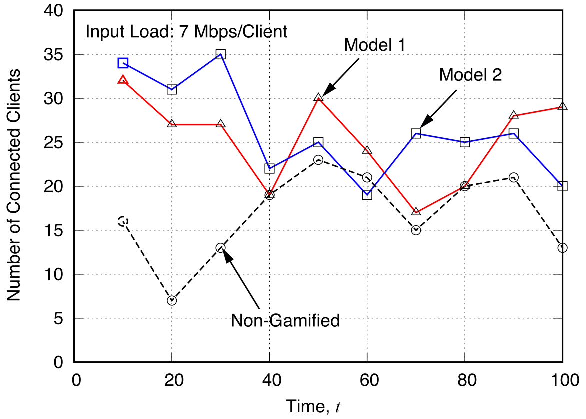


FIGURE 7. System throughput.



(a) System throughput



(b) Number of connected clients

FIGURE 8. Traffic simulation results.

are fairly compared. From Fig. 8a, the system throughput of the model 1 is always the best except at $t = 40$. In this case, with the model 1, multiple hosts are co-located in the same grid and connect with clients. The opportunities for the transmissions are decreased because these hosts communicate independently. In other words, frequent collisions occur, resulting in excessive retransmissions and packet loss. Such unexpected situations can be avoided by providing the constraint that the hosts should not gather in a close location. It could maintain the enhanced system throughput of the model 1. From Fig. 8b, the model 2 can support more clients than the model 1 most of the time. Although the number of connections strongly depends on the user distribution, we can confirm the certain tendency that it could contribute to improving the throughput performance. As a result, the effectiveness of the proposed gamified approach was validated in terms of the throughput performance.

VII. CONCLUSION

This paper introduced the concept of the gamified approach for encouraging autonomous D2D communication between mobile users. Although D2D communication is expected to be a promising solution for enhancing mobile coverage in the next generation cellular networks, it has been a significant issue to appropriately encourage the participation of mobile users in the autonomous approach. The proposed idea contributes for addressing this problem by encouraging mobile users to provide network connectivity for other mobile users based on the concept of a gamification. The game settings should be determined as regards the objective of D2D communication; it can be maximizing the number of connected users and/or maximizing the total system throughput, and other objectives can be employed. It was confirmed with computer simulations that gamification is a promising approach for encouraging autonomous D2D communication. The performance is determined by the definition of game-settings such as gain models and and provided information. The implementation and evaluation of the proposed idea constitute future work.

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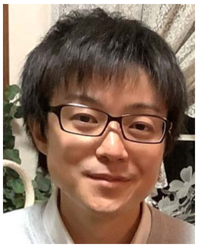

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