

A Study on Connectivity Evaluation Among Peer Groups in Pure P2P Networks

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Abstract— Recently P2P (peer-to-peer) network garners attention as a technology for developing a peer group by use of connection of peers which function as autonomously distributed and cooperative units virtualized from computer resources. In this paper, we focus on pure P2P networks which form peer groups by connecting peers without the need for intermediates. We execute performance evaluation by using computer simulation and propose a method to measure peer groups' connectivity utilizing mean number of connected peer groups without using peers' arrival and departure rates on peer groups.

Keyword— P2P, Pure model, Cluster model, Performance evaluation, Peer groups' connectivity

I. INTRODUCTION

RECENTLY P2P (peer-to-peer) network garners attention as a technology for developing a peer group by use of connection of peers which function as autonomously distributed and cooperative units virtualized from computer resources. JXTA [1], [2], SOBA [3], [4], and SIONet [5]-[8] are representative examples. Lately a P2P technology called blockchain [9] has attracted particular attention.

P2P network is classified into two types: pure model (flat model) [10], in which there is no intermediate to connect peer groups, and cluster model [11], in which there is an intermediate.

In the cluster model, an intermediate always connects peer groups, so there is no fragmentation among peer groups.

On the other hand, in the pure model, no intermediate exists to connect peer groups, so any peer connects peer groups by autonomously connecting with peers in other peer groups. Therefore, when a peer connecting peer groups departs from a peer group, the peer groups are broken up into fragments. As a result, it becomes difficult to share information among peer groups. Thus, in the pure model, it is important to evaluate connectivity among peer groups from the perspective of information sharing among peer groups [12], [13].

In this paper, we define connectivity among peer groups (%) as follows.

$$\frac{\text{Maximum number of connected peers}}{\text{Total number of peers}} \times 100 \quad (1)$$

In other words, the connectivity indicates how many percent of the peers are connected among all the peers, and no fragmentation among peer groups occurs when the connectivity is 100%.

While it is considered important to quantitatively evaluate the connectivity among peer groups in the pure model, some research papers [10], [12], [14]-[17] report on the evaluation of the connectivity among peer groups. However, in all of them, it is necessary to survey in advance "the arrival rate of peers in a peer group" and "the departure rate from a peer group," which are input parameters in the evaluation model of the connectivity. However, in this case, it is a big burden for the evaluators to obtain the arrival rate and the departure rate in advance by the actual survey.

Therefore, in this paper, we examine the performance of the evaluation model using computer simulations. We propose a method to calculate the connectivity among peer groups by using the mean number of connected peer groups without using the arrival and departure rates of peers as input parameters of the evaluation model [18]-[20].

The rest of this paper is organized as follows. The mechanism of the pure model is explained in section II. Next, in section III, we introduce a Community Coexistence Society (CCS), as an example of the pure model application to realize a sustainable welfare society in Japan. In section IV, we explain the performance evaluation model (simulation model) and scale to obtain the connectivity among peer groups. In section V, we show the results of the performance evaluation by simulation and discuss the results. Section VI concludes the paper and discusses future work.

II. MECHANISM OF THE PURE MODEL

In this chapter, we describe the mechanism for connecting peer groups in the pure model. In figure 1(a) and figure 1(b), we consider a virtualized peer as the minimum unit of autonomous distributed cooperation and a peer group formed as a set of peers.

To deepen the understanding of the pure model, we discuss the cluster model, which is a contrast to the pure model. In the cluster model, peer groups are connected to each other through an intermediate, as shown in figure 1(a). In this method, there is no fragmentation between peer groups unless

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the intermediate goes down, but the operating cost of the intermediate is often burdensome. Meanwhile, in the pure model, as shown in figure 1(b), peer A and peer B, which belong to peer group III, simultaneously participate in (belong to) peer group II and peer group I, respectively, so that peer α and peer Y can be connected through peer A and peer B. As a result, peer group I, peer group II, and peer group III can be connected. On the other hand, when peer A and/or peer B departs the peer group, the peer group may be fragmented, and cooperation and information sharing among peer groups may be disrupted.

Thus, although the pure model has the problem of fragmentation, it is unique in that it connects peer groups in a "loose," "flexible," and "autonomous distributed cooperation" form without the need for an intermediate, and it is widely used in a variety of fields because it does not require the operating costs of an intermediate.

There are many studies on fragmentation among peer groups. As examples of peer's departure from peer groups as a cause of fragmentation, a hardware failure of peers [14] and interruption of file exchange services [15] causes departure of peers from peer groups. Also, blockchain mining cost incurs peers' departure from a peer group and produces fragmentation of peer group [16], [17]. Furthermore, many examples of the application of the pure model concept to inter-operational and inter-organizational collaboration in real-world business models have been reported. For example, there is a reference [21] that reports that when bank employees (peers) multitask among departments (peer groups), such as the teller service department and the loan counselling department at a bank, fragmentation occurs when

employees depart from the department. Furthermore, reference [13] reports that hotel employees (peers) simultaneously participate in (belong to) different departments such as the front desk and the guest room cleaning (peer groups) to connect departments and that fragmentation occurs when hotel employees depart the department.

Although there is a problem of fragmentation, the trend towards applying the pure model, which does not require high operating costs for intermediates, to inter-organizational collaboration is notable in business categories involving customer service, such as bank tellers and restaurants, and in labor-intensive industries, such as hotels, lodging, nursing care, and so on. It has been reported that 24.4% of hotels and inns have introduced the pure model in recent years and have achieved positive results [22]. While these case studies are reported, in the next chapter we introduce CCS as an example using pure model inter-organizational collaboration in Japan.

III. AN EXAMPLE OF THE PURE MODEL USE

In this chapter, we introduce CCS as an example of use for improving the understanding of the pure model inter-organizational collaboration. In recent years, the number of single-person households in Japan has been increasing due to the aging of the population and the change in customs, such as parents and children living separately to respect privacy, and the isolation of individuals due to the reduction of welfare and medical services such as nursing care caused by the lack of financial resources due to the long-term economic stagnation has become a social problem.

So far, to prevent isolation, local public support organizations have provided information to residents by visiting households and making phone calls to confirm the safety of residents and to introduce them to consultation services. However, the number of users has decreased due to the declining population, and it has also become difficult to secure professional human resources, making it difficult to stably operate local public support organizations.

Therefore, the Japanese government advocates the establishment of a CCS in which information is shared by connecting groups such as public support providers, local businesses, local volunteer groups, and the homes of local residents in the pure model to prevent the isolation of individuals in the community [23].

In the past, public support has been based on information sharing in the form of the cluster model using an intermediate. For example, in the cluster model, as shown in figure 2(a), a facility for the disabled has members such as a staff and disabled persons who receive services. Likewise, in a agricultural corporation, there are a staff and laborers, and in a foreigner support volunteer organization, there are a staff and foreigner receiving support. In general, representative meeting is held for the purpose of cooperation and information sharing among the organizations, for example, once a month. This makes it possible for organizations to cooperate and share information with each other, and there is no fragmentation among the organizations unless the representative meeting is cancelled. Note that the representative meeting, organization, and members correspond to the intermediate, peer group, and peers, respectively, in figure 1(a).

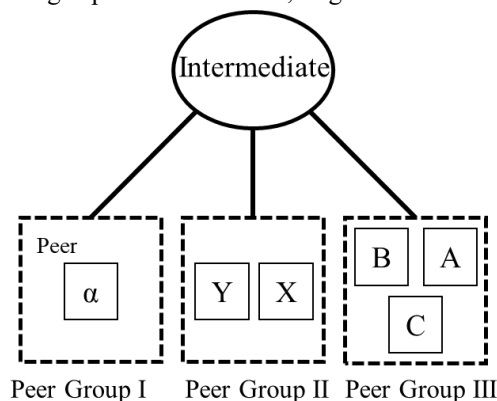


Fig. 1(a). Peer group connecting method (cluster model)

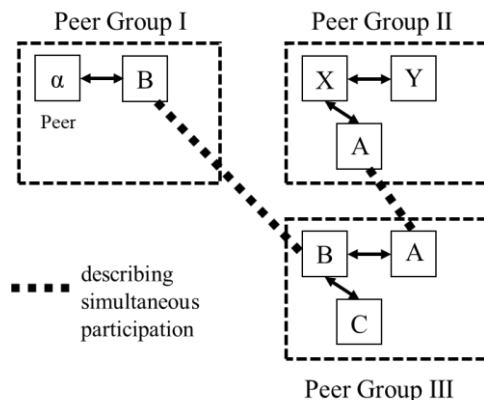


Fig. 1(b). Peer group connecting method (pure model)

However, the method of cooperation and information sharing among organizations through representative meeting has the following issues.

Issue 1: Delay in information transfer

Information on other organizations obtained by a staff member at a representative meeting is transferred from the staff member to the other members, which requires time for information sharing, resulting in a time delay.

Issue 2: Difficulty in creating a sense of ownership

Information about other organizations relayed by staff members tends to become someone else's business for members and members tend to lack a sense of ownership.

Issue 3: Overloading of staff members

Information is gathered by staff members who attend to a representative meeting, and the burden of information transmission is concentrated on them. Mental and physical exhaustion and employee turnover due to the concentration of workload on staff members have already become a social problem in the nursing care and medical fields [24].

In contrast, the peer group connecting method in the pure model, which is being used to realize a CCS, members of a facility for the disabled autonomously and simultaneously participate in or depart from an agricultural corporation or a foreigner support volunteer organization, and voluntarily share information with the members of the participating organizations. For example, as shown in figure 2(b), when disabled person C participates in the facility for the disabled and the agricultural corporation at the same time, and when laborer Y participates in the agricultural corporation and the foreigner support volunteer organization at the same time, the facility for the disabled, the agricultural corporation, and the foreigner support volunteer organization are connected as a result. Thus, collaboration and information sharing among the organizations become possible. Here, note that each

member and each organization correspond to a peer and a peer group, in figure 1(b), respectively.

This pure model solves the above three issues seen in the cluster model as follows.

Solution to issue 1: Speeding up information transfer

Compared to the representative meeting held periodically, the pure model has the advantage that information sharing is less likely to be delayed because the facilities for the disabled and the agricultural corporation are constantly connected through disabled person C.

Solution to issue 2: Creating ownership of information

Disabled person C, who belongs to a facility for the disabled, also belongs to an agricultural corporation, so he/she can have a sense of ownership of the information about the agricultural corporation.

Solution to issue 3: Reduction of staff workload

The information can be shared within the facility for the disabled by having C, who belongs to the facility for the disabled, simultaneously participating in the agricultural corporation and sharing the information obtained in the agricultural corporation without the involvement of staff A. This type of collaboration between the disabled and the agricultural corporation is widely called "agricultural welfare collaboration" and has been attracting attention in recent years as a place where the disabled can play an active and autonomous role [25]. In realizing a CCS, it is important for various entities including individuals to autonomously participate in the activities of not only one organization but also various organizations called "second place" and "third place," and the Japanese government is actively promoting the introduction of peer group collaboration in the community using the pure model [23].

On the other hand, a structural problem of the pure model, the connectivity decreases due to the fragmentation among the peer groups. For example, in figure 2(b), when a disabled person (peer) C departs from the agricultural corporation (peer group), the facility for the disabled peer group is separated from the peer group of the agricultural corporation and the foreigner support volunteer organization. In other words, information sharing among peer groups is disrupted, and at the same time, peers A, B, and C are isolated from other peers.

Therefore, in the pure model, quantitative evaluation of connectivity is important to prevent fragmentation. In previous studies, information on participation in and departure from each peer group (organization) by each peer (member) was collected over a long period of time to determine the arrival rate and the departure rate in advance [10], [12], [14]-[17], and computer simulations were used to calculate the connectivity among peer groups, which caused an excessive research cost.

Therefore, in this paper, we examine the performance of the evaluation model using computer simulations. We propose a method to calculate the connectivity among peer groups by using the mean number of connected peer groups without using the arrival and departure rates of peers as input parameters of the evaluation model [18]-[20]. The mean number of connected peer groups is the mean number of peer groups in which any peer participates at the same time.

The reason for using the mean number of connected peer groups as an input parameter for the evaluation model instead of the arrival and departure rates is its convenience. It is relatively easier to obtain the mean number of connected peer groups than to obtain the arrival and departure rates by a

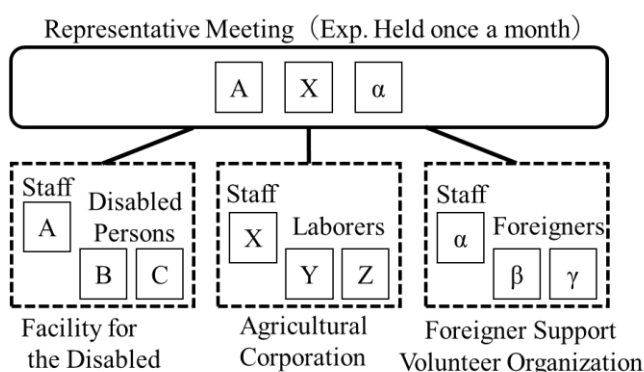


Fig. 2(a). Collaboration and information sharing among organizations through representative meeting

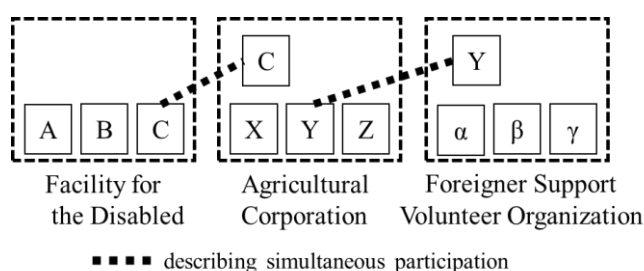


Fig. 2(b). Collaboration and information sharing among organizations in the pure model

measurement survey. For example, in a questionnaire survey, the question “How many groups, on average, did you belong to?” is easier to answer than “How often did you join in and depart from each group?” Hence, the proposed method requires less effort and cost to obtain the information needed to calculate the connectivity.

The next section describes the performance evaluation model used in simulations to calculate the connectivity using the proposed method.

IV. PERFORMANCE EVALUATION MODEL

In this section, we describe a performance evaluation model for quantitatively evaluating the connectivity among peer groups in the pure model.

Figure 3 shows the example of the performance evaluation model. This figure shows peer groups I to III formed by virtualized peers A to D as the minimum unit of autonomous distributed cooperation.

By peer B belonging to peer group I participates in peer group II, peer B participates in peer groups I and II simultaneously. As the same way, by peer C participates in peer groups II and III, peer A and peer D are connected via peer B and peer C. As the result of the connection among peer A, peer B, peer C and peer D, peer group I, peer group II, and peer group III are connected.

Thus, all peers independently participate in all peer groups with an arrival rate λ . Here, figure 3 shows the situation where peer B belonging to peer group I tries to participate in peer group II and peer group III with an arrival rate λ . As a result, it participates only in peer group II. We assume all peers in a peer group are always connected to each other. Therefore, we do not deal with the connection topology between peers in a peer group in this paper.

On the other hand, all peers independently depart from all peer groups to which they belong with a departure rate μ . For example, in figure 3, if peer B departs from peer group II, a fragmentation occurs between peer groups II-III, and peer group I. In this paper, for the sake of simplicity, we assumed that the arrival rate of each peer is all the same. And the departure rate of each peer is also all the same. We will discuss the performance evaluation model having different arrival and departure rate on each peer in the future work.

We explain the parameter and the performance evaluation scale on the performance evaluation model.

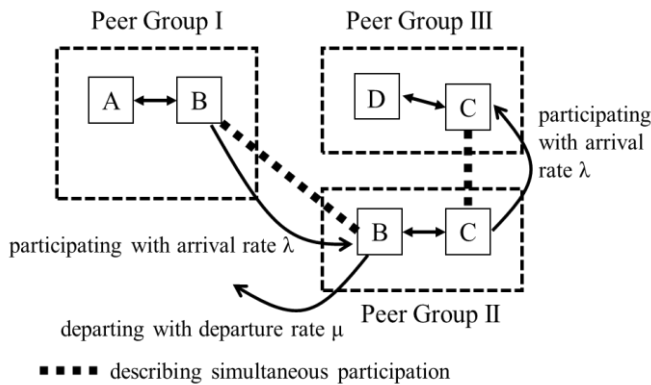


Fig. 3. Performance evaluation model

- The number of peer groups m : Total number of peer groups.
- The total number of peers n : The total number of peers, i.e., the sum of all peers participating in m peer groups. For example, $n=4$ in figure 3.
- Arrival rate λ : The arrival rate of each peer in each peer group. The mean number of times a peer participates in each peer group per unit of time. It is equal to the reciprocal of the mean time of participation in each peer group.
- Departure rate μ : The mean number of times that a peer departs from each peer group per unit of time. It is equal to the reciprocal of the mean time of sojourn in each peer group.
- Utilization rate ρ : Ratio of arrival rate to departure rate ($\rho = \lambda / \mu$)
- Maximum number of connected peers L : The maximum number of connected peers at a given point in time.
- Connectivity S : Percentage of peers that are connected among peer groups. $E\{L\}$ is the mean value of L , obtained by simulation. S is calculated from the following formula.

$$S = \frac{E\{L\}}{n} \times 100(\%) \quad (2)$$

- The number of simultaneously participated peer group on each peer K_i : The number of peer groups that the peer p_i ($i=1$ to n) is participating at the same time at a given point in time.
- The number of simultaneously participated peer group K : The mean number of K_i at a given point in time.
- The mean number of connected peer groups $E\{K\}$: The mean number of peer groups in which a peer participates at the same time. $E\{K\}$ is the mean value of K over the observation period, calculated by simulation.
- Peer's simultaneous participation rate R : The number of peer groups in which a single peer participates at the same time.

$$R = \frac{E\{K\}}{m} \times 100(\%) \quad (3)$$

For example, figure 4 shows a situation where there is a fragmentation among peer groups when $m=3$ and $n=6$. In peer group I, the number of connected peers is 2 because the p_1 and p_2 are connected. On the other hand, in peer group II and peer group III, the number of connected peers is 4

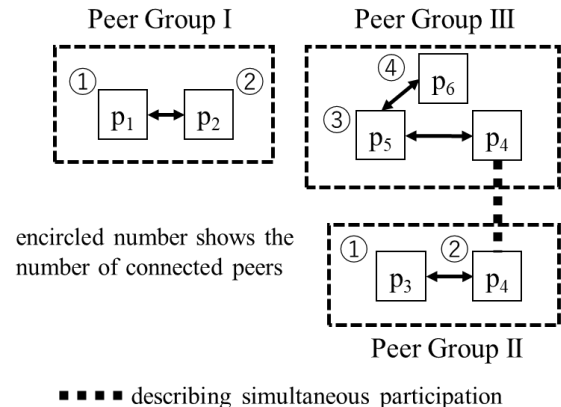


Fig. 4. Example of maximum number of connected peers (L) and number of connected peer groups (K_i).

because p3, p4, p5 and p6 are connected. Therefore, the maximum number of connected peers L is 4. Moreover, the number of simultaneously participated peer group on each peer K_i , which is the number of peer groups in which p_i participates simultaneously, is $K_1=1, K_2=1, K_3=1, K_4=2, K_5=1$ and $K_6=1$.

V. SIMULATION RESULTS AND DISCUSSION

In this section, we clarify that the connectivity S is calculated without using the arrival and departure rates (i.e., participation and departure information) from simulation results.

The convergence condition of the simulation is set to be within 3% difference from the previous $E\{L\}$ value.

Therefore, the convergence condition is given by the following formula where the time until convergence is the observation period.

$$\frac{|E\{L\}^{(t+\Delta t)} - E\{L\}^{(t)}|}{E\{L\}^{(t)}} < \varepsilon \quad (4)$$

Where t is any time in the simulation, Δt is the minimum unit time, and ε is the threshold.

The simulation was based on the performance evaluation model shown in figure 3. The simulator is implemented in C language, and the specification of the computer used for the simulation is presented in Table 1. The time required to obtain a single plot (point) in the graph was approximately 10 seconds, and the confidence interval $\pm 5\%$ was obtained by running the simulation three times for each plot in 95% confidence interval.

To ensure sufficient coverage, the number of peer groups m was set to $m=10$ and $m=30$, and the total number of peers n was set from $n=30$ to $n=1,500$.

Figure 5 shows the simulation results for $m=10$ and $n=30$. For both the utilization rate $\rho=0.4$ and $\rho=0.04$, the connectivity S does not depend on the departure rate μ , but on ρ , i.e., the ratio of λ to μ . Therefore, once ρ is determined, the connectivity S is independent of the departure rate μ . Therefore, figure 5 describes that robustness to ρ holds for the connectivity S .

Next, figure 6 shows the relationship between the departure rate μ and the mean number of connected peer groups $E\{K\}$ for $m=10$ and $n=30$, where $E\{K\}$ is the mean number of peer groups in which a peer is participating at the same time. Figure 6 shows that $E\{K\}$ does not depend on the departure rate μ , but on ρ , i.e., the ratio of λ to μ , for both the utilization rate $\rho=0.4$ and $\rho=0.04$. Therefore, once ρ is determined, $E\{K\}$ is uniquely determined. Figure 6 describes that robustness with respect to ρ holds for the mean number of connected peer groups $E\{K\}$.

Next, figure 7 and figure 8 show the simulation results of the departure rate μ and the peer's simultaneous participation rate R for $n/m=3$ ($m=10, n=30$ and $m=30, n=90$) and $n/m=50$ ($m=10, n=500$ and $m=30, n=1,500$), respectively, for the

utilization rate $\rho = 0.4$ and $\rho = 0.04$. From the respective figures, the peer's simultaneous participation rate R is dependent on the utilization rate ρ , since the same utilization rate ρ results in the same peer's simultaneous participation rate R .

Figure 9 is constructed by combining figures 5 and 6. Figure 9 describes that even without obtaining λ and μ , the mean number of connected peer groups $E\{K\}$ provides the connectivity S . For example, if each peer participates in 3 peer groups on average, then the connectivity S is approximately 100 %. This means that the derivation of λ and μ (setting of input parameters) by actual measurement is not necessary.

Finally, figure 10 compares $n/m=3$ ($m=10, n=30$ and $m=30, n=90$) and $n/m=50$ ($m=10, n=500$ and $m=30, n=1,500$) in the relationship between the mean number of connected peer groups $E\{K\}$ and connectivity S . The figure shows that the connectivity S depends on n/m , since the connectivity S is the

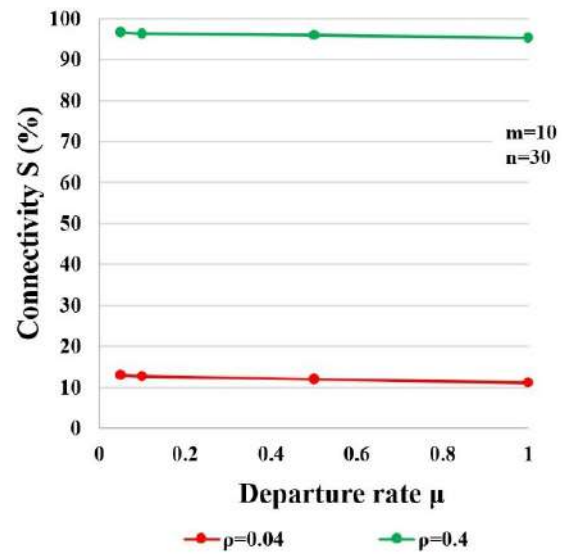


Fig. 5. Robustness to ρ on the Connectivity S

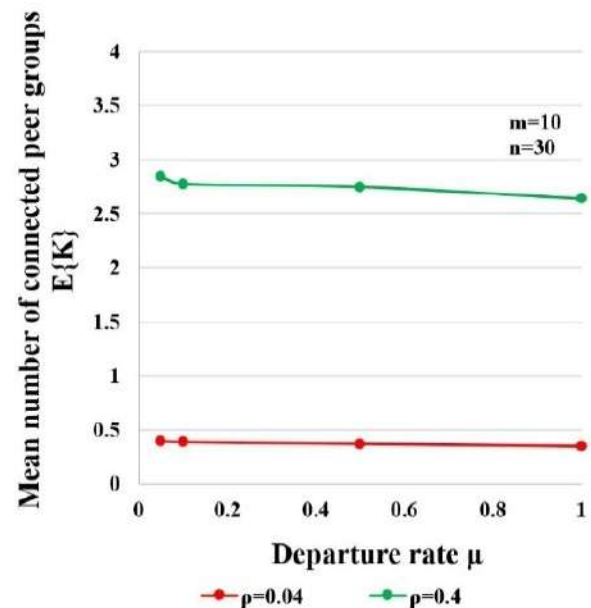


Fig. 6. Robustness to ρ on the Mean number of connected peer groups $E\{K\}$

Table 1. Simulation execution environment

Computer	Mac Book Pro (Late2013)
OS	OS X version 10.9.4
CPU	Intel Core i7 2.0 GHz
Memory	8GB (DDR3 1,600 MHz)
HDD	250 GB

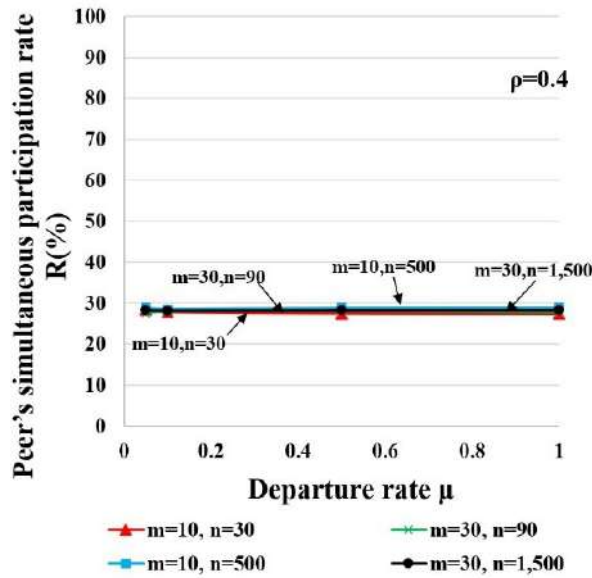


Fig. 7. Robustness to ρ on the peer's simultaneous participation rate R ($\rho=0.4$)

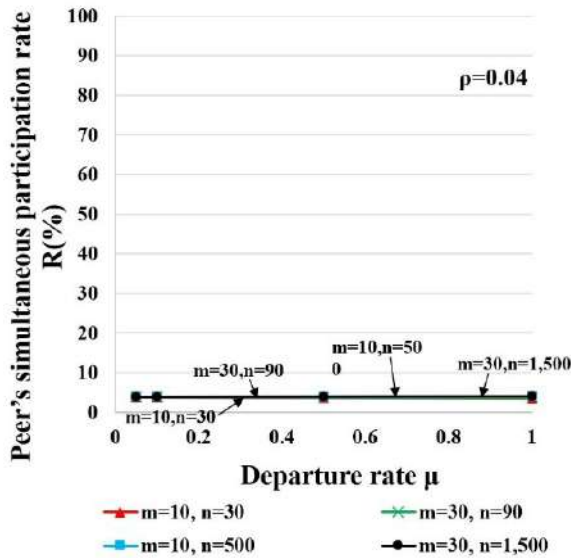


Fig. 8. Robustness to ρ on the peer's simultaneous participation rate R ($\rho=0.04$)

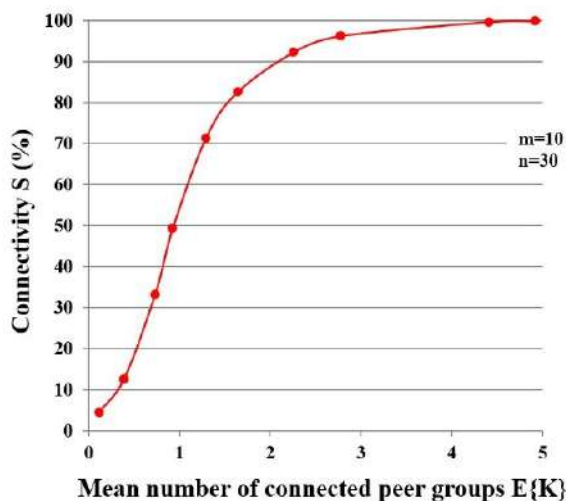


Fig. 9. Mean number of connected peer groups $E\{K\}$ vs. connectivity S

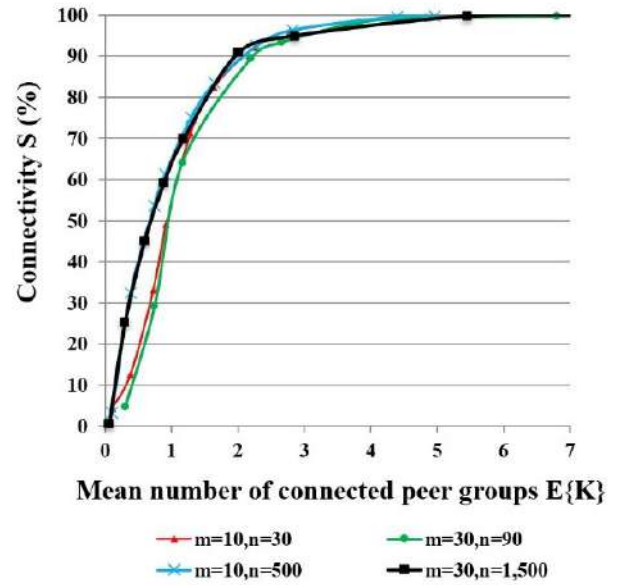


Fig. 10. Mean number of connected peer groups $E\{K\}$ vs. connectivity S ($n/m=3$, $n/m=50$)

same when n/m is the same. The larger n/m is, the faster the convergence of the connectivity S to the mean number of connected peer groups $E\{K\}$ becomes.

The simulation results provide the following findings.

- Even without investigating λ and μ as input parameters, the connectivity S is calculated from $E\{K\}$.
- The connectivity S depends not only on ρ , but also on the ratio of n to m (n/m). Therefore, if n/m is the same, the result will be the same.
- The convergence of the connectivity S with respect to the mean number of connected peer groups $E\{K\}$ is faster when n/m is large.
- Once n and m are determined, or once the ratio of n to m is determined, the mean number of connected peer groups $E\{K\}$, is obtained from the connectivity S . For the instance, figure 9 shows that the mean number of connected peer groups $E\{K\}$, is 2 to satisfy 90% of the connectivity S . In other words, a peer should participate in two peer groups in average.
- Once m , S , and $E\{K\}$ are determined, the required number of peers n is derived.
- The peer's simultaneous participation rate R depends on ρ .

VI. CONCLUSION

In this paper, we clarified through simulations that the peer connectivity is calculated without using the arrival rate or the departure rate in the pure model. Specifically, we found that the connectivity can be obtained from the average number of peer groups in which peers participate at the same time. Since the conventional method of evaluating the connectivity requires a large amount of time and effort to derive the necessary arrival and departure rates, we conclude that we can derive connectivity in a relatively short time through the quantitative evaluation of the connectivity.

In the future, we plan to evaluate simulations with a performance evaluation model that considers combination of

the peers and peer groups having various arrival and departure rates, i.e., the participation rate λ_{ij} of peer_{*i*} ($i=1,2,3...n$) in peer group_{*j*} ($j=1,2,3...m$) and the departure rate μ_{ij} .

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