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On the Contribution of Actively Collaborative Helpers in Large-scale P2P-VoD Systems

Yubao Zhang, Hui Wang, Pei Li, Zhihong Jiang, Yajie Liu

College of Information Systems and Management, National University of Defense Techonology, Changsha, P.R.China

{ybzhang, huiwang, peili, zhjiang, yjliu}@nudt.edu.cn

Abstract—Peer-to-Peer(P2P) Video-on-Demand(VoD) has been proved to be an promising solution to provide service for a large number of users. Nonetheless, the present P2P-VoD systems is typically capped by users' aggregate upload bandwidth and their limited capacity for assisting each other. This motivates our approach in which we utilize idle upload bandwidth resource of nodes, called helpers. Since helpers do not come with free preloaded content, they must consume the bandwidth resource to obtain content before providing service for users. In this paper, we investigate the tradeoffs between how much a helper downloads and how much it can upload for users from the viewpoint of collective behaviors of both users and helpers. We present analytical models respectively in the scenario that helpers are independent on each other and in the scenario that helpers can assist each other by providing demanded content. Furthermore, we view bandwidth amplifying effect of helpers as a function of download amount of helpers and get numerical solutions in typical settings for further insights. Finally, our experiments validate our analytical models.

Keywords-Peer-to-Peer; helper; Peer-to-Peer Video-on-Demand

1. Introduction

A new genre of P2P systems, P2P Video-on-Demand(P2PVoD), has not only received substantial recent research attention, but also been implemented and deployed with success in large-scale real-world streaming systems, such as PPLive [1], [5]. It has been proved to be as the help on the heels of the crisis that VoD systems with server-client infrastructure is very costly to provide service duo to significant increase in demand.

However, the recent explosive increase of Internet video received more and more attention, so much as being forecasted that it will dominate approximately 90% of Internet traffic by 2012. In the meantime, the desire of upgrading content from conventionally low quality to HD even SD videos has been placing striking burden on media severs. These have led to the bottleneck of P2P-VoD systems. Furthermore, in our previous work [7], we found that peers with random topology can hardly handle distribution of content by themselves.

Nevertheless, it is observed that there are other users who are not interested in any particular file but have considerably spare upload bandwidth. We will introduce such nodes into P2P-VoD systems and term them helpers. Helpers represent a rich source of upload capacity which can be employed for easing the bottleneck. Helpers are first introduced into a file download system by Wong [4] and then proved to be beneficial when they are introduced into P2P streaming systems [3]. For recently substantial research attention on P2P-VoD, Zhang et al. [6] developed a novel P2P-VoD architecture with helpers, where helpers form a volatile "server" which have the same service capacity for each segment. However, asynchronous playback as an inherent feature of P2P-VoD systems will dilute helpers' capacity for helping distribute the content. In this case, helpers can not exert their bandwidth amplifying effect.

An incentive mechanism should be established in the P2PVoD systems to encourage peers with idle upload bandwidth to join as helpers. However, we leave the question of incentive for helpers as future work.

Based on the efficient incentive mechanism, helpers actively participate the system and form a network to collaboratively disseminate the demanded content. If helpers are assigned to hold the most helpful content under soma a mechanism, helpers can achieve the best bandwidth amplifying effect. These centralized mechanisms, however, are costly. Consequently, we consider the special scenario that helpers download each segment with uniform probability. In what follows, it is natural to wonder that: How much segment should be downloaded by helpers to maximize their amplifying effect?

In this paper, we develop a tractable model to analyze the relation between download amount of helpers and amplifying effect of helpers. Two close-formed expressions are presented by performing steady-state analyses respectively in the scenario that helpers can not provide content for other helpers and on this basis, in the reverse scenario. Through these expressions, we are offered substantial flexibility to investigate the relation between download amount of helpers and amplifying effect of helpers. Furthermore, we view Contribution Ratio of helpers as a function of download amount of helpers and get numerical solutions in typical settings for further insights.

The remainder of this paper is organized as follows. Sec.II describes the basic concepts and assumptions in the analytical model. In Sec.III, we present our theoretical analysis with respect to the relation between Contribution Ratio and download amount of helpers. In Sec.IV, we get numerical solutions of optimization problems in Sec.III and resort to simulation experiments to validate our analytical results. Finally, Sec.V concludes the paper.

2. System Model

In this section, we present our mathematical model for the P2P-VoD systems with both regular peers and helpers, including the underlying assumptions and the hey notations summarized in Table I. We define CR(t) as the contribution ratio of helpers at time slot t, i.e., the ratio of contributed bandwidth resource for regular peers and consumed bandwidth resource from both server and regular peers, which illustrates the bandwidth amplification effect of helper network.

TABLE I. KEY NOTATIONS IN THE SYSTEM MODEL

Notation	Definition
$N_p(t)$	Number of regular peers in the system at time slot *t*.
$N_h(t)$	Number of helpers in the system at time slot *t*.
M	Number of segments in the system.
U_p	Upload capacity of each regular peer in segments per time slot.
R	number of concurrent requests issued by each regular peer within each time slot.
λ_p	Arrival rate of new regular peers.
λ_h	Arrival rate of new helpers.
U_h	Upload capacity of each helper in segments per time slot.
A_{pp}	Number of neighborhood regular peers that each regular peer connects to.
A_{hp}	Number of neighborhood regular peers that each helper connects to.
A_{ph}	Number of neighborhood helpers that each regular peer connects to.
A_{hh}	Number of neighborhood helpers that each helper connects to.
c	Download amount of each helper in segments.
D_i	Number of requests received in the *i*th helper.
$B_{in}(t)$	Bandwidth consumed by helpers in segments at time slot *t*.
$B_{out}(t)$	Bandwidth contributed by helpers in segments at time slot *t*.
$CR(t)$	Contribution ratio of helpers at time slot t($B_{out}(t)$=$B_{in}(t)$).

We first consider steady-state helper-less P2P-VoD systems with server, tracker and a collection of homogeneous regular peers. The whole M segments from one file are preloaded on the server. A newly arriving regular peer queries the tracker to obtain a list of peers who are interested in the same video file. Note that tracker chooses randomly among the existing peers when it receives a request for a list of peers. The new regular peer then contacts these peers to establish connections with them. Each regular peer can maintain a maximum number of neighbor, which is proportional to its upload bandwidth. Since we consider the homogeneous scenario that each regular peer has Up maximal upload connections, the maximum neighbor number of each regular peer can be denoted as A_{pp}. Note that each connection has a fixed mean throughput and upload bandwidth is the only bottleneck. We also assume that regular peers participate the system following the Poisson distribution with parameter λ_p and then depart the system after they perform completely continuous playback from the very beginning segment to the *M*th segment.

To alleviate the server loading, we are motivated to utilize the idle upload bandwidth resource of helpers who are not interested in the file but are willing to contribute their upload bandwidth and a little amount of cache, as Fig.1 shown. New helpers arrive at rate λ_h and stay in the system for time following exponential distribution with mean λ_h. A helper joins the system just like a regular peer except that it is not willing to utilize too much cache to download the whole file. Assume that the download amount of each helper is c. Helpers uniformly cache the segments so as to have uniform ability to serve requests for each segment. Furthermore, each new helper is assumed to be able to saturate the cache of capacity c segments in the right time slot when they just arrive. We then define $B_{in}(t)$ as the bandwidth consumed by helpers from both server and regular peers at time slot *t* and $B_{out}(t)$ the bandwidth contributed to regular peers by helpers at time slot t. Consequently, the contribution ratio of helpers CR(t) can be defined as the ratio of $B_{in}(t)$ and $B_{out}(t)$, i.e., CR(t) = $B_{out}(t)/B_{in}(t)$. It is straightforward that $B_{in}(t)$ is linearly dependent on the download amount c of helper. Similarly, the download amount c is clearly related with the capacity for helpers to upload for regular peers, thus it has strong relation with $B_{out}(t)$. Therefore, the contribution ratio CR(t) is the function of the helper download amount c, i.e., CR(t) = f(c; t).

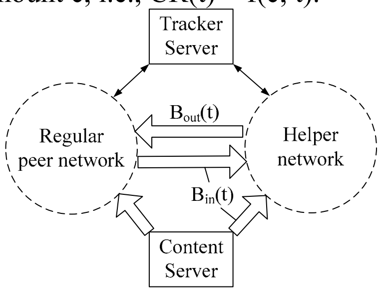


Figure 1 The P2P-VoD system with helpers.

As stated before, our focus is to maximize the contribution ratio of helpers by deriving the optimal download amount of helpers in the scenario with regular peer network of random topology and helper network. Helpers join the system, download a fixed amount of segments and randomly connect with A_{hp} regular peers and A_{hh} other helpers to offer service. Note that, A_{hp} is different from A_{ph}, since the former represents the neighborhood regular peers that each helper holds and the later represent the neighborhood helpers that each regular peer holds. Clearly, we get $A_{hp} = N_p A_{hp} / N_h$ under the steady-state where $N_p = N_p(t)$ and $N_h = N_h(t)$ hold. In other words, steady state represents the state that arrival rate equals departure rate of nodes in the system. We then assume that each helper offers the same service capability for the requests from other helpers as that for the requests from regular peers. Additionally, helpers uniformly download segments and ensure the same ability to serve requests for each segment.

3. Analysis of Optimal Download Amount of Helpers

The basic model proposed in previous section sets the stage for us to further analyze the relation between the contribution ratio *CR(t)* and the download amount c of helpers. In this section, we present the steady-state study on choosing optimal download amount of helpers to maximize the contribution ratio of helpers in P2P-VoD systems with both regular peers and helpers. Since we focus on the steady-state analysis, *CR(t)*, $B_{in}(t)$, $B_{out}(t)$, $N_p(t)$ and $N_h(t)$ are all independent on time slot in steady state. In the following, we derive the optimal helper download amount in two different scenarios: in the simple scenario, networked helpers do not assist each other, i.e., $A_{hh} = 0$; in the practical scenario, helpers assist each other, i.e., $A_{hh} \neq 0$.

3.1 Simple Scenario: Helpers do not Assist each other

We first consider the simpler scene that the neighborhood connections from helpers to helpers equal to 0, i.e., $A_{hh} = 0$. In this case, helpers only download content from regular peers and server, i.e., the bandwidth resource consumed by each helper is fixedly c segments. Recall that each helper is assumed to consume bandwidth resource only when they just arrive, hence in any time slot of steady state, $B_{in} = \lambda_h \cdot c$. Similarly, helpers only upload for regular peers. To derive the steady-state contributed bandwidth of all helpers, we label helpers from 1st to N_h th and consider the i*th* helper. Let b_{out}^i denote contributed bandwidth of the i*th* helper. Therefore, $B_{out}^i = \sum_{i=1}^{N_h} b_{out}^i$. We then present the derivation of b_{out}^i in steady state.

Consider a specific time slot t of steady state. In this time slot, each regular peer issues demands to neighbors, including regular peers and helpers. In reality, each regular peer sends a fixed R requests for a series of segments needed for future playback, as Fig. 2 shown. However, from the viewpoint of a sufficiently long period, each regular peer could be regarded as sending R requests for only one needed segment within one time slot of steady state.

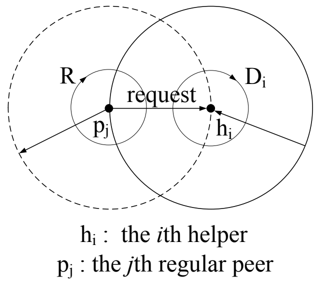


Figure 2 Request: The dashed circle represents neighborhood nodes of the j*th* regular peer, while the solid circle represents neighborhood nodes of the i*th* helper. Clearly, aforementioned nodes include both regular peers and helpers. Each regular peer issues a total of R requests to neighborhood nodes and consequently, the i*th* helper receives D_i requests from neighborhood regular peers.

Given the ith helper receives a total of D_i requests, labeled from 1st to D_ith. Clearly, how much segments a helper holds determines how much requests it receives from neighbors. D_i is a random variable that follows a binomial distribution with parameters $(A_{hp}, c/M)$, and an expected value of $E[D_i] = A_{hp} \cdot c/M$. The sufficient conditions of helper's successful response for a specific request include:

1) This helper has sufficient upload bandwidth.

2) The other (R−1) nodes including regular peers and helpers that received the same requests do not offer service.

Let P_1^{ij} and P_2^{ij} denote the probability for the i*th* helper to satisfy the first and the second conditions for the j*th* request, respectively. Therefore,

$$b_{out}^i = \sum_{j=1}^{D_i} P_1^{ij} P_2^{ij}$$

1) Deriving the probability of satisfying the first sufficient condition: Since the upload bandwidth of ith helper is limited, two separate cases for P_1^{ij} are considered as follows.

Case 1: $D_i \leq U_h$, i.e., the i*th* helper has ability to respond all requests. In this case, $P_1^{ij} = 1$, $j \in [1, D_i]$. Clearly, the probability that this case holds is $\sum_{m=0}^{U_h} (1-c/M)^{A_{hp}-m} (c/M)^m$ where a helper connects to m regular peers who need segments this helper holds and (A_{hp} -m) who do not need any segment.

Case 2: $D_i > U_h$, i.e., the i*th* helper has not ability to respond all requests. In this case, $P_1^{ij} = U_h/D_i$ ($j \in [1, D_i]$) since each node whether helper or regular peer, is assumed to uniformly respond to each request received. Similarly, the probability that this case holds is $(1-c/M)^{A_{hp}-m} (c/M)^m$, where $m \in [U_h+1, A_{hp}]$.

In conclusion, $P_1^{ij} = \min\{1, U_h/D_i\}$. From this expression, P_1^{ij} is clearly independent on the parameter j.

Furthermore, we can derive P_1^i as follows:

$$P_1^i = \sum_{m=0}^{U_h} (1-c/M)^{A_{hp}-m}(c/M)^m + \sum_{m=U_h+1}^{A_{hp}} (U_h/m)(1-c/M)^{A_{hp}-m}(c/M)^m$$

Focusing on the collective behavior of homogeneous helper network, we get $P_1^i = P_1$ from the above expression. P1 can be regarded as the average response capacity of helpers.

2) *Deriving the probability of satisfying the second sufficient condition:* In what follows, we proceed with deriving P_2^{ij}. Firstly, assume that the other (R−1) nodes of the second condition consist of nh helpers and np regular peers. We respectively label these n_h helpers from 1st to n_h*th*, and these n_p regular peers from 1st to n_pth. From the previous analysis, the probability that none of those homogeneous n_h helpers responds the request can be expressed as $\prod_{l=1}^{n_h}(1-P_1^l) = (1-P_1)^{n_h}$. Note that n_h is a random variable that follows a binomial distribution with parameters (A_{ph}−1, *c/M*). Hence, E[n_h]=$(A_{ph}-1)c/M$.

For simplicity, we consider the average behavior of the regular peer network in steady-state to derive the probability that none of the other np regular peers offers service. By Little's Law, the regular peer population in steady-state satisfies $N_p = \lambda_p \cdot M$. Since our sole focus is the amplification effect of helpers, we are more interested in the collective behavior of the regular peer network rather than the individual peer behavior. Recall that we assume all regular peers leave only when they complete the playback of all segments in numerical order, i.e., each regular peer stay in the system M time slots. Based on the fixed arrival rate λ_p, the age of Np regular peers uniformly ranges from 0 to M time slots. In the following theorem, we will derive the probability that a regular peer can not obtain any upload resource when it sends R requests to multiple neighbors at a specific time slot. Our approach is influenced by that in [2].

Theorem 1: *For a regular peer network, we can derive the average probability* $\zeta(t)$ *that a specific peer that have been in the system for t time slots could not obtain any download connection from other regular peers:*

$$\zeta(t) = 1 - \frac{U_p}{R(1+\ln\frac{N_p}{N_p-\lambda_p t})}$$

For a better flow of presentation, we will leave out the proof of the above theorem, which can refer to our previous work [7]. Since helpers are assumed to uniformly cache the segments, the neighborhood regular peers of each a helper can be regarded as uniformly distributing in the playback time range (0,M). Therefore, let $t_1, t_2, \cdots ; t_{D_i}$ denote the time in ascending order that D_i regular peers, who sent request to the specific ith helper, stay in the system.

In this point, we can express b_{out}^i as follows:

$$\begin{aligned} b_{out}^i &= \sum_{j=1}^{D_i} P_1^{ij} P_2^{ij} \\ &= D_i P_1^i \sum_{j=1}^{D_i} P_2^{ij} \\ &= D_i P_1^i \sum_{j=1}^{D_i} \prod_{l=1}^{E[n_h]} (1-P_1^l)\zeta(t_j) \\ &= D_i P_1^i D_i \prod_{l=1}^{E[n_h]} (1-P_1^l) \sum_{j=1}^{D_i} \zeta(t_j) \end{aligned}$$

Then, we derive the aggregate bandwidth resource contributed by helpers in a specific time slot of steady-state:

$$\begin{aligned} B_{out} &= \sum_{i=1}^{N_h} b_{out}^i \\ &= \sum_{i=1}^{N_h} (D_i)^2 P_1^i \prod_{l=1}^{E[n_h]} (1-P_1^l) \sum_{j=1}^{D_i} \zeta(t_j) \end{aligned}$$

To study the collective behavior of helper network, we replace D_i with the expected values E[D_i]. Similarly, we are more interested in the collective behavior of the regular peer network. Consequently, we calculate the expected value E[ζ] of $\zeta(t)$, t ∈ (0,M) by converting the discrete summation to continuously integral equation.

$$E[\zeta]=\frac{1}{M}\int_0^M \zeta(t)dt$$
$$=1-\frac{1}{M}\int_0^M \frac{U_p}{R(1+\ln\frac{N_p}{N_p-\lambda_p t})}dt$$

Based on our previous work [7], we can obtain $E[\zeta]=1-\frac{N_p}{RM}\{\text{Gompertz Constant}\}$, where *Gompertz Constant* ≈ 0.59. Therefore,

$$B_{out}=N_h(E[D_i])^2\sum_{j=1}^{(A_{hp}\cdot c/M)}\zeta(t_j)P_1(1-P_1)^{(A_{ph}-1)\cdot c/M}$$
$$=N_h(E[D_i])^2(A_{hp}\cdot c/M)E[\zeta]P_1(1-P_1)^{(A_{ph}-1)\cdot c/M}$$

Therefore, the optimal helper contribution problem in the proposed P2P-VoD system can be formulated as the following close-formed expressions:

$$CR=B_{out}/B_{in}$$
$$B_{in}=\lambda_h\cdot c$$
$$B_{out}=N_h(E[D_i])^2(A_{hp}\cdot c/M)E[\zeta]P_1(1-P_1)^{(A_{ph}-1)\cdot c/M}$$
$$P_1=\sum_{m=0}^{U_h}(1-c/M)^{A_{hp}-m}(c/M)^m+\sum_{m=U_h+1}^{A_{hp}}(U_h/m)(1-c/M)^{A_{hp}-m}(c/M)^m$$
$$E[D_i]=A_{hp}\cdot c/M$$
$$E[\zeta]=1-0.59\cdot\frac{N_p}{RM}$$

Clearly, CR can be viewed as the function of c. We will get the numerical solution by implementing MATLAB in Sec. IV since the function is so complicated that the precise solution is extremely complex.

3.2 Practical Scenario: Helpers Assist each other

We further venture into the analysis of the optimal download amount of helpers when helpers are able to provide content for other helpers, that is, there exist available neighborhood connections in helper network. Let B_{hh} denote the amount of bandwidth cycling in the helper network. To discern the consumed and contributed bandwidth from those of the previous scenario, let $\overline{B}_{in}$ and $\overline{B}_{out}$ represent the the consumed and contributed bandwidth of helper network in this scenario. Then, it holds

$$\overline{B}_{in}=B_{in}-B_{hh}$$
$$\overline{B}_{out}=B_{out}-B_{hh}$$

Likewise, the mathematical model in this scenario can be presented as follows:

$$CR=\overline{B}_{out}/\overline{B}_{in}$$

To this end, we first calculate B_{hh}. Recall that, each helper is assumed to offer the same service capability for the requests sent by other helpers as that for the requests sent by regular peers. Therefore, we can calculate B_{hh} by similar method of calculating B_{out} in the previous subsection. As a consequence of the different demand patterns between helpers and regular peers, number of requests which helpers send to other helpers is rather distinct with number of requests which regular peers send to helpers. As stated previously, the requests received by *i*th helper that are sent by neighborhood regular peers is a random variable D_i following a binomial distribution with parameters (A_{hp},*c/M*). In this scenario, the number of requests received by *i*th helper that are sent by both regular peers and other helpers is a random variable denoted by D_i following a binomial distribution with parameters ($A_{hh}+A_{hp}$,*c/M*). Hence, E[D_i] = ($A_{hh}+A_{hp}$)*c/M*. For simplicity of presentation, let $A_h=A_{hh}+A_{hp}$, where A_h represents the number of all neighbors of a helper.

$$B_{hh}=\frac{A_{hh}}{A_h}N_h(E[D_i])^2(A_{hp}\cdot c/M)E[\zeta]P_1(1-P_1)^{(A_{hh}-1)\cdot c/M}$$
$$P_1=\sum_{m=0}^{U_h}(1-c/M)^{A_{hp}-m}(c/M)^m+\sum_{m=U_h+1}^{A_h}(U_h/m)(1-c/M)^{A_h-m}(c/M)^m$$
$$E[D_i]=A_h\cdot c/M$$
$$E[\zeta]=1-0.59\cdot\frac{N_p}{RM}$$

Likewise, we will also present the numerical solution in Sec. IV rather the precise solution due to complexity.

4. Numerical Calculation and Simulation Validation

In this section, we compare the numerical results of both models mentioned previously with simulation results to examine the relationship between download amount of helpers and Contribution Ratio of helper network and further illustrate the application to protocol design.

We build a simulation program based on our aforementioned model assumption. There are N_p homogeneous regular peers and N_h homogeneous helpers. In our experiments, regular peers continually participate the system, perform a complete in-order playback and depart the system once finishing playback. Helpers join the system following Poisson distribution with parameter λ_h and stay in the system following exponential distribution with parameter μ_h. Playback rate of video file is 1 segment per time slot. Due to the limitation of space, we present experiment results of only one scenario and more experiment results refer to our technical report.

4.1 Exp. A: Comparing analytical result with simulation result in the scenario that helpers do not assist each other

Our first objective is to validating the analytical model in the scenario that helpers do not assist each other by comparing the numerical result with simulation result. From Fig.3, we observe numerical results match well simulation results. Furthermore, one important observation is that there exists the optimal helper download amount which makes the maximal helper Contribution Ratio. However, the optimal helper download amount lies somewhere close to *M*. Therefore, we practically achieve the conclusion that more segments helpers download, more benefits they will bring for the P2P-VoD systems. In addition, the figure shows that in the tail of analytical curve, especially when $c = 500$, the analytical result approaches 0. Clearly, it does not accord with reality as our simulation results show. The reason that accounts for the deviation is that the rationale of our analytical model is based on collective behavior of the whole helpers. Nonetheless, when helpers each hold much sufficient segments, they compete fiercely for contributing their idle upload bandwidth for regular peers.

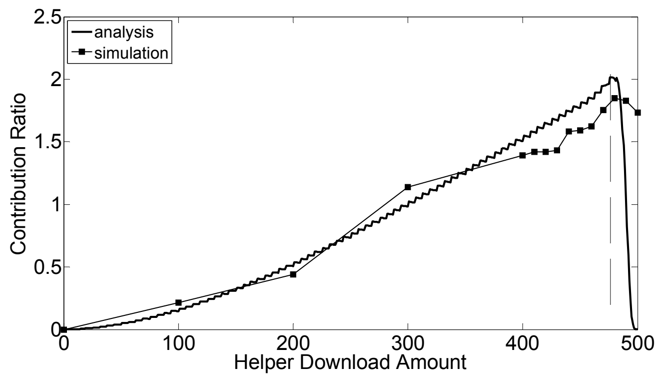


Figure 3 Comparing analytical result without neighborhood connections from helpers to helpers with simulation result, where we set $M = 500$, $N_p = 1000$, $N_h = 100$, $A_{pp} = 20$, $A_{ph} = 20$(therefore, Ahp = $20N_p/N_h$),$R = 5$, $U_p = U_h = 1$ and $c \in [0,M]$.

4.2 Exp. B: Comparing analytical result with simulation result in the scenario that helpers assist each other

We then compare analytical result with simulation result in the scenario that helpers assist each other. As Fig.4 shown, we observe that: (1) numerical results of our analytical model quite accord with simulation results; (2) Like in the above scenario, the optimal helper download amount, in this scenario, exists and also lies somewhere close to M; (3) More importantly, Contribution Ratio in this scenario is almost double times than that in the scenario that helpers do not assist each other when M = 500, which means that connections between helpers facilitate the contribution capacity of helper network rather weaken the capacity. Likewise, the tail of the analytical curve in this scenario, especially when c = 300 and c = 500, deviates the reality and approaches 0. The reason that accounts for the deviation is the same as that mentioned previously, therefore, we will not give unnecessary details.

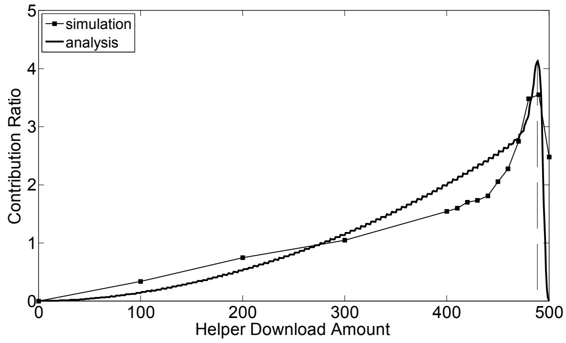
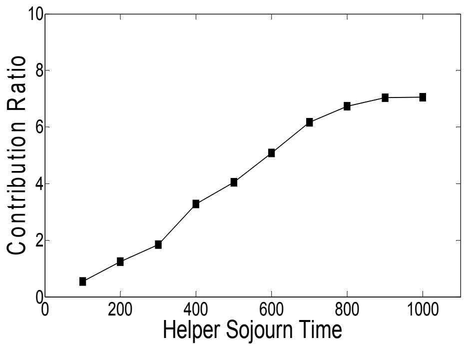


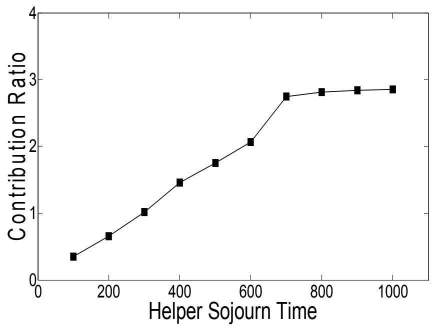
Figure 4 Comparing analytical result without neighborhood connections from helpers to helpers with simulation result, where we set M = 500, Np =1000, Nh = 100, App =20, Aph = 20(therefore, Ahp = 20Np/Nh),R = 5, Up = Uh = 1, Ahh = 10 and c∈[0,M].

4.3 Exp C: Effects of Sojourn Time of Helpers

We further examine the effects of helpers' sojourn time. After downloading c segments by consuming bandwidth resource of system, helpers stay in the system for a certain time and contribute their idle upload bandwidth to provide service for regular peers or other helpers. Clearly, the time that helpers stay in the system is closely related with amount of segments which are contributed by helpers. From Fig.5, we find that in both scenarios, Contribution Ratio of helpers is almost linearly related with average sojourn time of helpers, especially when the sojourn time is relatively low. Furthermore, one observation is that Contribution Ratio practically reaches standstill when sojourn time of helpers is relatively large. The reason that results in the standstill is that a relatively large sojourn time leads to a considerably large number of helpers who compete for providing service for regular peers.



(a) Without connections between helpers



(b) With connections between helpers

Figure 5 Effects of helpers' Sojourn Time: M = 500, N_p = 1000, N_h =100, A_{pp} = 20, A_{ph} = 20(therefore, A_{hp} = 20N_p/N_h), A_{hh} = 10,R = 5, U_p = U_h = 1, c = 500 and we vary average sojourn time of helpers from 0 to 1000.

4.4 Practical Implementation

In here, we briefly discuss the applicability of helpers in real P2P-VoD systems. There are two points we would like to make.

First, helpers should download almost the whole file under the circumstances that each segment has uniformly demanding probability since the optimal download amount of helpers lies somewhere close to the whole segment, as our analytical models and simulations shown. However, helpers is not willing to contribute so many cache capacity for not interested video content. A solution is to partition the whole M segment of one file into K subfiles and helpers each download approximately $\lceil M/K \rceil$ segments. Additionally, in real world, the demand pattern is hardly uniformly distributing, which leads to lower Contribution Ratio of helpers. Application of network coding has been proved to be helpful. Extending work to combining network coding with helper network remains part of our ongoing and future work.

Second, our analytical models and simulations show that connections between helpers make nearly double times Contribution Ratio. Therefore, helpers implemented in real world should first satisfy other helpers' requests to enable them to contribute their idle upload bandwidth. In what follows, helpers will prioritize urgent demand of regular peers and then respond other requests with uniform probabilities.

5. Conclusion

This paper presents analytical models respectively in the scenario that helpers are independent on each other and in the scenario that helpers can assist each other by providing demanded content. Through analytical models, we get numerical solutions and obtain following insights: (1) there indeed exists the optimal download amount of helpers, which, however, lies somewhere close to the number of the whole segments. Consequently, helpers' download amount can be decreased by partitioning the entire file into sub-files. (2) Helpers' capability of assisting each other drastically facilitates the role that helpers play in helping content distributing. As shown in our experiments, helpers can exert considerably amplifying effect that should not be overlooked even under the circumstances that they are in loosest management that helpers participate the system, randomly download a fixed number of segments and upload segments for demanding regular peers or other helpers.

6. Acknoledgement

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7. References

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