An Efficient Data Replication Scheme for Peer-to-Peer Video Streaming Over Wireless-Mesh Community Networks

JEN-WEN DING[1], WAN-TING WANG[1], AND CHU-FU WANG[2]
[1]*Department of Information Management, National Kaohsiung University of Applied Sciences, Kaohsiung, Taiwan*
[2]*Department of Computer Science, National PingTung University of Education*
E-mail: *jwding@cc.kuas.edu.tw*, *eumenides0207@msn.com, cfwang@mail.npue.edu.tw*

Abstract

Wireless mesh networks (WMNs) are expected to play an important role in the next–generation Internet because of its several advantages, such as self-organization, high capacity, low deployment cost and low maintenance cost. In this paper, we discuss how to provide robust home-to-home on-demand streaming on the basis of WMNs. A key challenge for such a community-based P2P multimedia system is how to efficiently place and replicate video clips across different home devices in the face of frequent online/offline behavior of users. In this paper, we propose an efficient data replication scheme called H2-VIP for home-to-home video streaming. H2-VIP computes the optimal number of replicas of video blocks. Our simulation results show that the proposed scheme can largely reduce the failure rate of home-to-home streaming at the cost of a small amount of extra storage space.

1. Introduction

Because of the rapid growth in wireless technology, it is now feasible to build a multi-hop wireless network over metropolitan area distances. Such a network is also known as wireless mesh network (WMN) [1]. Several companies have tried to apply WMN technology to build community networks, by which neighbors can connect their home networks together [2]. There are several advantages of using wireless mesh community networks. First, because home networks can communicate with each other to forward data packets, there is no need for each individual home to subscribe to the Internet access from Internet Service Providers (ISPs). Instead, the community can share a high-bandwidth Internet access. By doing so, the cost of home Internet access can be effectively reduced. Second, home devices usually have large storage space. The spare space of each home device can collectively form a large community storage farm. The community storage farm can then accelerate the speed for disseminating cached information that is relevant to the community. In this paper, we consider a home-to-home multimedia-on-demand system, as shown in Fig. 1. In this architecture, popular videos can be stored in the community storage farm. Most of the time, users can obtain the requested video data form neighboring homes. Occasionally, users need to obtain the required data from the Internet if the requested data cannot be found in the storage farm. By doing so, we can reduce the startup latency for accessing video data. Also, we can improve the quality of video streaming without worrying the impact caused by the dynamic Internet behavior. Lastly, we can reduce the in/out traffic for the community.

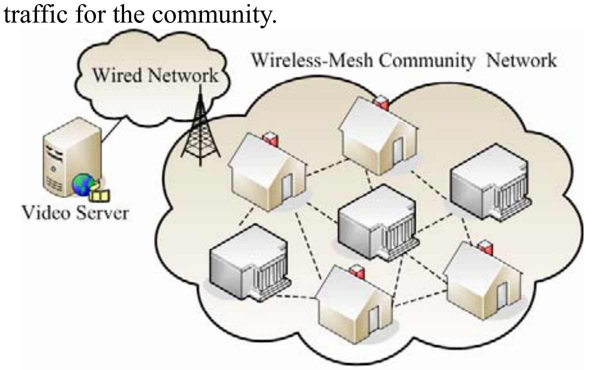

Fig. 1 System architecture

In [3], the data placement and replication problem for home-to-home multimedia-on-demand system have been discussed, and they proposed a scheme called H2O. However, in H2O, it is assumed that all home devices must be on-line. In practice, some users get used to turning off home devices during nights and vacations, which will significantly decrease the performance of home-to-home multimedia-on-demand

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system. In this paper, we develop a new data replication scheme, called home-to-home video clip replication scheme (H2-VIP), which can efficiently deal with the frequent online/offline behavior of users at the cost of a small amount of storage space.

The rest of this paper is organized as follows. Section 2 provides an overview of the recent development of P2P video streaming and the current replication approach. Section 3 describes our proposed scheme, H2-VIP (Home-to-Home Video clIp rePlication). Section 4 presents the performance evaluation results of the proposed scheme. Finally, Section 5 concludes this paper.

2. Related Work

Over the past few years, many studies discuss how to deliver video streams using P2P networking to largely reduce the cost of client-server architecture or CDN-based architecture. Well-known examples of P2P on-demand streaming include P2Cast [5] and P2VoD [6]. A major challenge for P2P streaming is the frequent online/offline behavior of peers. Recently, Ghandeharizadeh et al.[3], discussed the issue of providing P2P on-demand video streaming over mesh network. They solved the problem of the long multi-hop delay caused by delivering video clips between peers (or home devices). They proposed a data placement and replication scheme, called H2O, to minimize the total storage space required for three typical network topologies, linear, grid, and graph, as shown in Fig. 2.

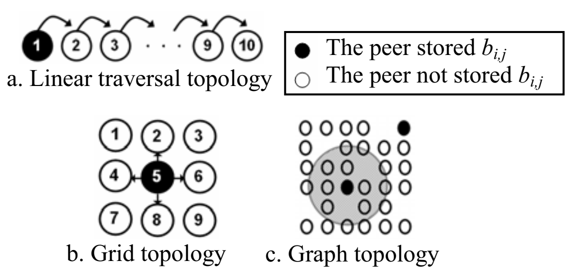

Fig. 2 Three topologies of H2O

3. H2-VIP System Design

This section details the proposed H2-VIP scheme, which can largely increase the reliability of the home-to-home multimedia-on-demand system at the cost of a small amount of extra storage space. H2-VIP also takes into account the popularity of videos because the popularity of videos determines the number of peers accessing the videos. H2-VIP is based on H2O. Section 3.1 describes the system model and introduces the notation used in this paper. Section 3.2 explains the rationale of H2-VIP.

Table 1. Notation Table

N_p	Number of devices
N_v	Number of video clips
S_v	Size of a video (MB)
S_b	Size of a block (MB)
N_b	Number of block
h	Time to retrieve a block that is one-hop away
D	Display time of a block
$r_{i,j}$	the based number of copies of a block b_i
$H_{i,j}$	Number of copies of a block $b_{i,j}$
α	the total extra-storage in the network
$r_{i,j}^*$	the needed extra-replicate for the block b_i of the video v_j
P_j	The popularity of video v_j (*Zip f* distribution)
β	The joined or left rate of a peer

3.1. Video Clip Replication Model

The main procedure of H2-VIP is similar to that of H2O. The main difference between the two schemes is twofold. First, in H2O, each video clip is treated equally. In H2-VIP, the popularity of different videos is taken into account. Second, H2-VIP computes a different value for the number of replicas of each video clip. In H2-VIP, the following steps are carried out:

1. Each video clip, $V_j, 1 \le j \le N_v$, is divided into N_b equal-sized blocks of size S_b.
2. The first block of each video, $b_{1,j}$, $1 \le j \le N_v$ is stored on all nodes.
3. For each block $b_{i,j}$, $i \ne 1$, computes its delay tolerance $H_{i,j}$, $1 \le j \le N_v$, where $\left\lfloor H_{i,j} = \frac{(i-1)D}{h} \right\rfloor$.
4. According to $H_{i,j}$, computes $r_{i,j}$, the number of replicas of block bi.
5. Compute $r_{i,j}^*$, the extra number of replicas of video block $b_{i,j}$, $1 \le j \le N_v$, according to the video access probability P_j, $1 \le j \le N_v$, and the total extra storage space, α, allocated to improve the system reliability.
6. Finally, all blocks are scattered over all peers (or home devices) according to $H_{i,j}$, $1 \le j \le N_v$.

We use Zipf distribution [4] to model the video probability distribution. The popularity of video j is computed as follows, where s is the skew parameter.

$$f_j = \frac{1/j^s}{\sum_{n=1}^{N_v} 1/n^s} \quad (1)$$

3.2. The Optimal Replication Scheme

H2-VIP takes the join/leave behavior of peers into account. When several nodes are shutdown or removed unexpectedly in the network, requesting peers will not be able to obtain and display the requested video blocks. Let β denote the offline probability of a peer. To solve this problem, we can use extra replicas to increase the availability of block b_i within H_i hops. That is, the requesting peers can obtain b_i from two or more nodes within H_i hops without worrying the failure of peer nodes. Let $r_{i,j}$ denote the number of replicas of block $b_{i,j}$ derived by H2O, and let $r_{i,j}^*$ to denote the extra number of replicas of block $b_{i,j}$ of the video V_j derived by H2-VIP. For ease of discussion, let $C_i = 1/r_{i,j}$. Then the total failure rate of fetching blocks can be calculated by Equation (2), which is equivalent to Equation (3).

$$\min \sum_j \sum_i \beta^{1+C_i \times r_{i,j}^*} \times P_j \quad (2)$$

$$\min \sum_j \sum_i \beta^{1+C_i \times r_{i,j}^* + \log_\beta P_j} \quad (3)$$

Let α denote the extra space allocated for the extra number of replicas, we have the storage space constraint, as shown in Equation (4). Note that α is an adjustable system parameter. If the community storage farm is large, a large value of α can be used accordingly.

$$\sum_j \sum_{i-1}^{N_b} r_{i,j}^* \le \alpha \quad (4)$$

Since there exists an upper bound for extra storage space, the summation of the exponents in Equation (4) is a constant. Therefore, Equation (4) has the minimum value when all exponents are equal to each other, as shown in Equation (5), where A is a certain constant.

$$\forall i, j : 1 + C_i \times r_{i,j}^* + \log_\beta P_j = A \quad (5)$$

Therefore, the optimal value of $r_{i,j}^*$ can be obtained by Equations (4) and (5).

4. Performance Evaluation

4.1. Simulation Model

In this subsection, the performance metrics, environment setup, and compared replication approach are described. The network topologies used in the simulations were generated by randomly distributing 200 peers over a linear, a Grid, and a 1000×1000 m^2 square coordinate Graph topology. We join ten 2-min video clips consisted of 60 blocks (N_b =60): $b_{1,j}$, $b_{2,j}$,…, $b_{60,j}$ with different popularity. The skew parameter s of Zipf distribution is set to 0.729. We set peer offline probability β=0.3, and one-hop delivery time h=0.5. The size of a block is fixed at 1 MB S_b =1 MB resulting in a display time of 2 s for each block, D=2. In our simulation, H20 replication approach [3] was compared with H2-VIP.

4.2. Simulation Results

When some peers leave, they may cause video playback discontinuity for other peers. Especially, when the leaving peers holds popular video blocks, this phenomenon is more serious. Therefore, H2-VIP will allocates more replicas $r_{i,j}^*$ of video v_j in the network to increase network stability. In Fig. 3-5, when we allocate an extra 35% of the space required by H20 as the extra space, we can observe that the more popular videos will have lower failure rates to ensure steady quality.

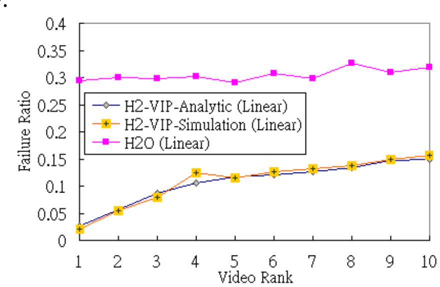

Fig. 3 Linear model: the failure rate versus the video rank

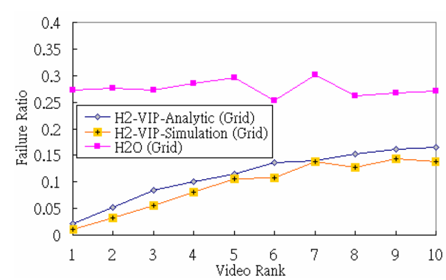

Fig. 4 Grid model: the failure rate versus the video rank

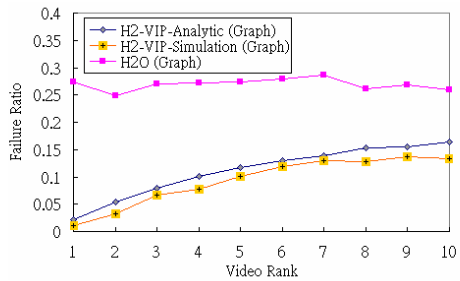

Fig. 5 Graph model: the failure rate versus the video rank

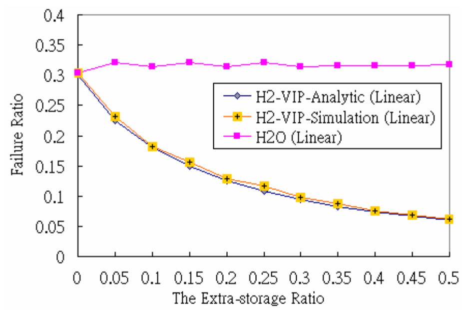

Fig. 6 Linear model: the failure rate versus the extra-storage rate

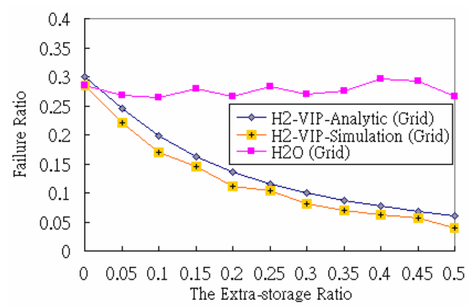

Fig. 7 Grid model: the failure rate versus the extra-storage rate

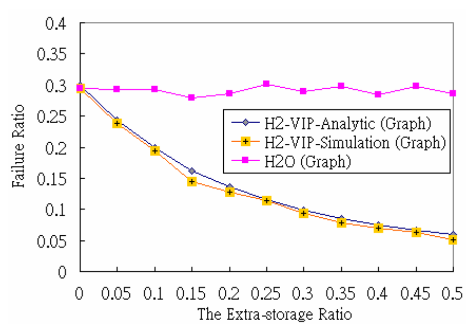

Fig. 8 Graph model: the failure rate versus the extra-storage rate

To decrease the failure probability of fetching requested blocks, we use extra replicas to increase the number of block $b_{i,j}$ within $H_{i,j}$. In Fig. 6-8, we observe that we only allocate an extra 50% of the space required by H20 as the extra space, and in the event we will reduce the failure rate to below 0.07 and provide a stable video quality.

5. Conclusion

In this paper, we discuss the design of a home-to-home multimedia-on-demand system over wireless-mesh community network. Previous studies have solved the long delay problem for accessing video blocks caused by multi-hop relay. However, the peer join/leave problem is not addressed. In this paper, we develop a novel replication scheme, called H2-VIP, which can minimize the system failure rate by allocating a small amount of extra space. The main merit of H2-VIP is that it can compute the optimal number of replicas of video blocks such that the overall system failure rate can be minimized subject to a limited storage space. We have conducted a series of simulations. Our simulation results show that the failure rate in the network can be significantly reduced by H2-VIP. Also, the simulation results validate the analytic model of H2-VIP.

6. References

[1] I.F. Akyildiz and X. Wang, "A survey on wireless mesh networks", *IEEE Communications Magazine*, vol. 43, no. 9, Sept. 2005, pp. 23-30.

[2] Self-Organizing Neighborhood Wireless Mesh Network list. http://research.microsoft.com/mesh/.

[3] S. Ghandeharizadeh, B. Krishnamachari, and S. Song, "Placement of Continuous Media in Wireless Peer-to-Peer Networks", *IEEE Transactions on Multimedia*, vol. 6, no. 2, April 2004, pp.335-342.

[4] L. Breslau, C. Pei, F. Li et al., "Web caching and Zipf-like distribution: evidence and implications," *in Proceedings of IEEE INFOCOM*, Apr. 1999, pp. 126-134.

[5] Y. Guo, K. Suh, J. Kurose *et al.*, "P2Cast: peer-to-peer patching scheme for VoD service", in Proceedings of the 12th international conference on World Wide Web, May. 2003, pp. 301-309.

[6] T. T. Do, K. A. Hua, and M. A. Tantaoui, "P2VoD: providing fault tolerant video-on-demand streaming in peer-to-peer environment", *IEEE International Conference on Communications*, June 2004, pp. 1467-1472.