Maximum Utility Peer Selection for P2P Streaming in Wireless Ad Hoc Networks

Eren Gürses
School of Computer Science,
University of Waterloo,
Waterloo, ON N2L 3G1, Canada
egurses@uwaterloo.ca

Anna N. Kim
Center for Quantifiable QoS in Comm. Systems,
Norwegian University of Science and Technology,
N-7491, Trondheim, Norway
annak@q2s.ntnu.no

***Abstract*—In the recent years, the peer-to-peer (P2P) overlay network has been a promising architecture for multimedia streaming services besides its common use for efficient file sharing. By simply increasing the number of peers, the P2P overlay network can meet the high bit rate requirements of multimedia applications. Optimal peer selection for newly joining peers is one of the important problems, especially in wireless networks which have limited resources and capacity, since the peer selection process has a direct impact on the throughput of the underlay network and the co-existing unicast traffic. In this paper we tackle the problem of peer selection for streaming applications over wireless ad hoc networks. We devise a novel peer selection algorithm which maximizes the throughput of the underlay network, and at the same time makes P2P streaming friendly towards the co-existing data traffic. The proposed receiver based Rate allocation and Peer Selection (RPS) algorithm is derived using the network utility maximization (NUM) framework. The algorithm solves the peer selection and rate allocation problem distributedly while optimally adapting the medium access control (MAC) layer parameters and is easily extensible to large P2P networks. Simulation results show that by using the proper price exchange mechanism, the peer receivers can effectively maximize the throughput of the underlay network by intelligently selecting its source peers.**

***Index Terms*—P2P streaming, peer selection, wireless ad hoc networks, dual decomposition, cross-layer design.**

I. Introduction

Ever since their first appearance, Peer-to-Peer (P2P) type file sharing and streaming has gained enormous amount of popularity. The basic concept of a P2P network is that, instead of having clients connect to a specific server, a group of participating peers form an overlay network. The peers are logically connected and share files and streaming applications by acting both as clients and servers. As more peers participating the network, the service capacity increases. Undoubtedly, by simply increasing the number of streaming peers, P2P applications can consume large portion of the available bandwidth. How to optimally allocate the network resources in this case is clearly an important issue. One way to address this problem is through intelligent peer selection or topology control. The classic tree-type topology [1] uses a hierarchical structure, which is sensitive to peer changing dynamics. The mesh topology [2], which is based on the tree structure, aims to maximize the spatial diversity in terms of distributing data amongst a peer's neighbours and subsequently offers higher throughput than the standard tree topology. In [3], a distributed algorithm was proposed to construct the overlay topology of participating peers such that the utilization of the available bandwidth of each streaming peer is maximized. Simulation results showed the algorithm can be applied over various link delays and capacities. It was argued that random selection of peers using local information, as proposed in [4],[5] does not offer global optimality, although the algorithms are robust to variations in peer participation. However, as we shall show later, this is actually not the case and network level optimality *can* be reached with local information exchange in a P2P network. The resulting peer selection is not necessarily *random*, but is scalable and does not have a rigid, predefined structure.

In this paper, we focus our attention to P2P streaming in wireless ad hoc networks. The motivation is two fold. First, as the wireless networks constitute a large portion of the next generation communication network, efficient mechanisms for supporting P2P streaming and file sharing in the wireless environment is needed. Wireless channels in general have limited bandwidth, are error prone and can be time varying, while the wireless nodes are often battery powered. The P2P network topology and the peer selection process has greater impact to its underlay network. Second, there has been surprisingly few existing work on P2P peer selection and topology control in wireless networks. Test results shown in [6] revealed that in a wireless access network, the network congestion caused by heavy P2P traffic results in excessive delays for co-existing delay sensitive applications. No feasible solutions however were proposed and the network topology was a very simplified one. Leung et al addressed a wireless P2P system and proposed a topology control protocol that links energy efficiency and incentive offering through exchange of objective metrics information between peers [7]. The protocol is designed for P2P file sharing, so latency constraints in streaming applications are not considered. The so-called "super peers" network [8] model was proposed to augment the lack of centralized resource planning for supporting P2P in mobile ad hoc networks and hybrid algorithm (selection of super and normal peers) [9] was developed which offer selection and switching of super peers for better load balancing. The proposed algorithm is not optimized in regards to network utility. And again, as we will reveal in this paper, that centralized resource planning was not

978-1-4244-2324-8/08/$25.00 © 2008 IEEE.

This full text paper was peer reviewed at the direction of IEEE Communications Society subject matter experts for publication in the IEEE "GLOBECOM" 2008 proceedings.

a necessity in this type of networks.

Our goal in this paper is to develop a distributed scheme that optimally creates the overlay network (i.e. peer selection) and assigns rates to relevant peers to support P2P streaming of a *bit rate scalable* content over a wireless ad hoc network. However the optimization of the overlay network is achievable with the information exchange between lower layers of nodes from the underlay network. Recently, generalized network utility maximization (GNUM) framework [10] has appeared as a versatile tool for modeling such cross-layer interactions. In this paper we extend the GNUM formulation to incorporate the peer selection and rate allocation issues of P2P multimedia streaming and proposed a distributed and receiver based Rate allocation and Peer Selection (RPS) algorithm. To achieve this we make use of the congestion information from the lower layers of the nodes of the underlay network. Besides this, we addressed the MAC layer optimization of the underlay network derived from [13] which has a direct impact on the overlay network's throughput. However MAC layer issues are not considered as a part of the RPS algorithm.

The rest of the paper is organized as follows. We first present the abstract topology of a wireless ad hoc network with P2P streaming in Section II, along with the associating parameters. The GNUM formulation is then presented in Section II-C. The solutions and simulation results are presented in Section III and IV respectively, followed by in depth discussions in Section V. We then conclude the paper and give an outlook of possible future work.

II. System Model

We consider a network topology as depicted in Figure 1. Here P2P streaming is conducted over a wireless ad hoc underlay network with N nodes which are connected through a total of L *physical* wireless links. Each node in the network acts as sender, receiver or both. The nodes which are forming the P2P overlay network may also generate/transmit unicast flows. One should keep in mind that P2P network is only a logically connected network where packets are actually carried out in the underlay wireless network, exactly in the same way as non-P2P packets.

We denote the set of sources, receivers and the wireless links as $\mathcal{S}$, $\mathcal{R}$ and $\mathcal{L}$ respectively. Amongst the total S sources, there is a set of $\mathcal{P}$ participating peers. When new peers are selected to join the streaming session, they are included in $\mathcal{P}$ and topology is updated. We denote the total number of source peers a receiver k is streaming from as S_k; and $\mathcal{S}(k)$ as the corresponding source peer set. The streaming source, for example video, is encoded using a FGS (fine granularity scalable) coder [11][1]. From each source peer, the receiver k is streaming at rate x_{ks}. We define the flow rate vector $x^{(k)}$ for receiver k as $x^{(k)} = [x_{k1}, ...x_{kS_k}]^T$. Note that by simply setting $S_k = 1$, the term x_{ks} describes the unicast flows. In the following subsections, we first introduce the necessary parameters and notations on each layer, then present the resulting GNUM formulation.

[1]We use FGS as an example scalable coder. Other types of scalable coder such as the layered coding can also be incorporated with minor modifications

A. Application, Transport and Network Layer Parameters

Selecting the appropriate streaming peers is the responsibility of the application layer in a P2P network. It can be done for example, by random peer selection or using application layer peer statistics without specific optimization metric.

The aim of our proposed algorithm however, is to perform peer selection and rate allocation that maximize the throughput of the underlying network while obtaining the *best streaming performance* [2] for peers. Information from lower layers of the underlay network, namely transport and MAC layers, as explained below, turns out to be a necessary part of optimization process.

Generally speaking, when a standard TCP algorithm is used at the transport layer, it operates independently on each source-to-receiver flow. However, in our model we use the flow rate vector $x^{(k)}$ to jointly manage peer selection and rate allocation tasks at the application layer. Calculation of x_{ks} is done in coordination with other source-to-receiver flows. Note that $x_{ks} = 0$ denotes no rate is allocated between source s and receiver k which also implies source s is not selected as a peer for k. In addition, since we considered FGS coding for video sources, it is possible that each source has a different version of the required FGS video with a source rate of $b_s^{(k)}$. For any receiver peer k, without loss of generality, we can order all its source peers for non-decreasing $b_s^{(k)}$ such that $x_{k1} \le b_1^{(k)}; x_{k1} + x_{k2} \le b_2^{(k)}; ... \sum_{s=1}^{S_k} x_{ks} \le b_{S_k}^{(k)}$ and relate the application layer video rate to the rate allocation parameter. The total rate received by receiver k is given as $\sum_{s \in \mathcal{S}} x_{ks}$, which is the sum of all source flows requested from the different source peers.

At the network layer, we define per-receiver *connectivity matrix* $H^{(k)}$, for receiver k which describes the physical connectivity of the S_k peers that receiver k can be logically connected with and the overall connectivity matrix as $H = [H^{(1)} H^{(2)} \dots H^{(k)}]$ which is the receiver based interpretation of the underlay network's routing matrix. There are then in total $S' = \sum_{k=1}^{R} S_k$ number of flows for the total R receivers. The dimensions of the per receiver matrix $H^{(k)}$ and overall connectivity matrix H are $L \times S_k$ and $L \times S'$ respectively. For each matrix $H^{(k)}$, the entries $h_{l,s}^k$ are defined as 1 if link l is used by traffic $s \to k$ and 0 otherwise.

B. MAC Layer Issues

In this section we introduce the parameters related to the optimization of the Medium Access Control (MAC) protocol which has a direct impact on the network throughput.

Similarly in [13], we visualize the contending links of the network using a conflict graph shown in Figure 2. In this graph, we label each wireless link of a given topology (Fig.1) with a unique number and represent it as a

[2]Best streaming performance means the maximum video bit rate a receiver peer can get. We assume dropped packets are retransmitted and each receiver has enough playout buffer in order to prevent packet losses due to late arrivals

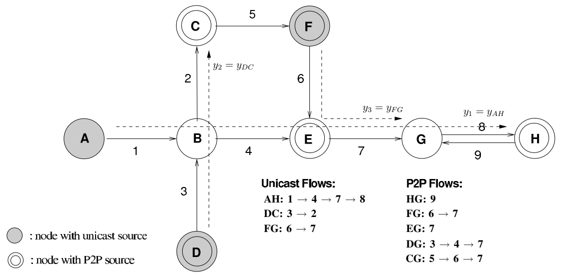

Fig. 1. A sample wireless ad hoc network topology

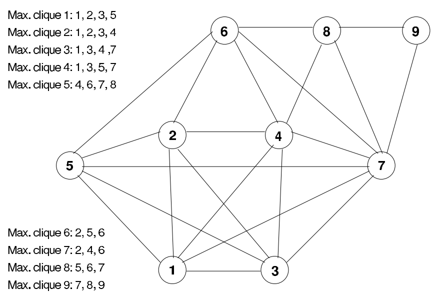

Fig. 2. Conflict graph corresponding to the topology

link node where each line connecting them means these two links interfere with each other. All link nodes that are connected to *each other* form a subgraph that is referred to as a *clique*. A maximal clique is a complete subgraph that is not contained in any other complete subgraph. Hence the list of maximal cliques for the topology is given as $\big\{\{1,2,3,5\},\ \{1,2,3,4\},\ \{1,3,4,7\},\ \{1,3,5,7\},\ \{4,6,7,8\},$ $\{2,5,6\},\ \{2,4,6\},\ \{5,6,7\},\ \{7,8,9\}\big\}$ where interference range is limited only to the neighboring nodes.

We define a_l as the parameter that determines the successful medium access probability on link l after taking the effect of collisions into account. This parameter can be interpreted as the percentage of time (or probability) that link l captures the medium for transmission among the other contending links within a maximal clique n where $\mathcal{L}(n)$ denotes the set of links in clique n. We define a conflict matrix F of dimension $M \times L$ which describes how the different wireless links are contending for the channel where M and L denote the total number of maximal cliques and links in the network respectively. The entries f_{nl} of conflict matrix F take the value of 1 for $l \in \mathcal{L}(n)$ and 0 otherwise. For each maximal clique n, the sum of medium access probabilities of links that conflict should satisfy the inequality $\sum_{l\in\mathcal{L}(n)} f_{nl}a_l \le \epsilon_n$, where $\epsilon_n \in [0,1]$ denotes the usable portion of a channel after excluding the effect of collisions. $\epsilon_n = 1$ corresponds to the case of perfect scheduling where there is no collision.

C. Generalized Network Utility Maximization Formulation

We describe the GNUM formulation in (1)-(6). We take the bottom-up approach to explain this set of equations. Equations (5)-(6) give the values that x_s and a_l can take. Then in (4), the constraint on peer's upstream rate determined by available FGS video source rate is given, which is previously discussed in Section II-A. Note that $\mathcal{S}(s,k)$ denotes set of all source peers available to receiver k and has video rate smaller than $b_s^{(k)}$. The second constraint in (3) describes the access constraint imposed by the MAC layer as given in detail in Section II-B. The first constraint in (2) concerns many layers but essentially states that traffic traversing wireless links is bounded by the amount of bandwidth each node actually acquires for transmission through the corresponding MAC protocol. Note that $h_{ls}^{(k)}$'s are the entries of connectivity matrix and c_l is the information theoretic link capacity where $a_l c_l$ is the effective link capacity observed above the MAC layer. And finally, the utility function $U_k(.)$ is a function of the *total flow* each peer receiver k gets. The solution to (1)-(6) yields the optimal rate allocation-peer selection, x and channel access, a, parameters that maximize the total network throughput.

$$\max_{x,a} \quad \sum_k U_k\Big(\sum_s x_{ks}\Big) \tag{1}$$

$$\text{s. t.} \quad \sum_k \sum_s h_{ls}^{(k)} x_{ks} \le a_l c_l,\ \forall l \in \mathcal{L} \tag{2}$$

$$\sum_l f_{n,l} a_l \le \epsilon_n,\ \forall n \in \mathcal{F} \tag{3}$$

$$\sum_{s' \in \mathcal{S}(s,k)} x_{ks'} \le b_s^{(k)},\ \forall k \in \mathcal{P} \text{ and } s \in \mathcal{S}(k) \tag{4}$$

$$x_{min} \le x_{ks} \le x_{max}, \quad \forall k \text{ and } s \in \mathcal{S}(k) \tag{5}$$

$$0 \le a_l \le 1,\ l \in \mathcal{L} \tag{6}$$

The general utility function $U(x)$ for $x \ge 0$ in (7) is strictly concave and differentiable and can represent different form of fairness in the network for different values of $\alpha = 0, 1, 2, ...$

$$U^{\alpha}(x) = \begin{cases} (1-\alpha)^{-1}x^{1-\alpha} & \text{, if } \alpha \neq 1 \\ \log x & \text{, otherwise} \end{cases} \tag{7}$$

III. Optimization Using Dual Decomposition

The above mentioned joint peer selection and rate allocation problem together with MAC optimization is what we call a "primal problem" in nonlinear programming. In this section we introduce the distributed RPS (receiver based Rate allocation and Peer Selection) algorithm that solves this problem. The Lagrangian dual of primal problem is very useful for the implementation of such *distributed* algorithms and it has the same solution to the original primal problem if convexity holds. Due to lack of space we skip the convexity proof of optimization problem in (1)-(6). The proof itself is quite straightforward with basic theorems of convexity.

In order to obtain the dual problem, we first write the Lagrangian $L(\lambda,\nu,x,a)$ as in (8) associated with the problem (1) by relaxing constraints (2) and (3) with Lagrange multipliers $\lambda = [\lambda_1 \dots \lambda_L]$ and $\nu = [\nu_1 \dots \nu_M]$.

$$L(\lambda,\nu,x,a) = \sum_{k\in\mathcal{R}} U_k\Big(\sum_{s\in\mathcal{S}} x_{ks}\Big) - \sum_{l\in\mathcal{L}}\sum_{s\in\mathcal{S}} \lambda_l h_{ls}^{(k)} x_{ks} + \sum_{l\in\mathcal{L}} \Big\{\lambda_l a_l c_l - \sum_{n\in\mathcal{F}} \nu_n f_{nl} a_l\Big\} + \sum_{n\in\mathcal{F}} \nu_n \epsilon_n \tag{8}$$

This full text paper was peer reviewed at the direction of IEEE Communications Society subject matter experts for publication in the IEEE "GLOBECOM" 2008 proceedings.

TABLE I
DISTRIBUTED RPS ALGORITHM WITH MAC OPTIMIZATION

Receiver Algorithm (Overlay Network):

Step R0 : Each receiver k initializes $x_{ks} = 0$ for $x_{min} \leq x_{ks} \leq x_{max}$.

Step R1 : Each receiver $k \in \mathcal{P}$ calculates it's source rate vector $x^{(k)}$ by solving the following local constrained optimization problem.

$$\max_{\substack{\sum_{s' \in \mathcal{S}(s,k)} x_{ks'} \leq b_s^{(k)},\ \forall s \in \mathcal{S}(k) \\ x_{min} \leq x_{ks} \leq x_{max},\ \forall s \in \mathcal{S}(k)}} U_k\Big(\sum_{s \in \mathcal{S}(k)} x_{ks}\Big) - \sum_{l \in \mathcal{L}} \sum_{s \in \mathcal{S}(k)} \lambda_l h_{ls}^{(k)} x_{ks} \quad (10)$$

Step R2 : If x_{ks} or λ_l does not converge, go to Step R1, else wait.

Link Algorithm (Underlay Network):

Step L0 : Link l initializes $\lambda_l, \nu_n, a_l = 0$ for $0 \leq a_l \leq 1$ and $\lambda_l, \nu_n \geq 0$.

Step L1 : On each link l, calculate congestion price, λ_l using gradient methods, and feed back λ_l to receivers/sources.

$$\lambda_l(t+1) = \Big[\lambda_l(t) - \beta_\lambda (a_l c_l - \sum_k \sum_s h_{ls}^{(k)} x_{ks})\Big]^+ \quad (11)$$

Step L2 : Iterate on Step L2 until convergence (MAC optimization [13])

$$a_l = \frac{\lambda_l c_l - \sum_n \nu_n f_{nl}}{2\delta_a}\ ;\ \nu_n(t+1) = \Big[\nu_n(t) - \beta_\nu(\epsilon_n - \sum_l f_{nl} a_l)\Big]^+ \quad (12)$$

Step L3 : If a_l, λ_l, ν_n do not converge, go to Step L1, else wait.

Then, the dual function $D(\lambda, \nu)$ can be expressed as the maximum of the Lagrangian $L(\lambda, \nu, x, a)$ w.r.t. primal variables x and a while conforming to the constraints:

$$D(\lambda, \nu) = \max_{\substack{\sum_{s' \in \mathcal{S}(s,k)} x_{ks'} \leq b_s^{(k)},\ \forall k \in \mathcal{P},\ s \in \mathcal{S}(k) \\ x_{min} \leq x_{ks} \leq x_{max},\ \forall k,\ s \in \mathcal{S}(k) \\ 0 \leq a_l \leq 1,\quad \forall l \in \mathcal{L}}} L(\lambda, \nu, x, a) \quad (9)$$

Equipped with the expressions (8) and (9), we can write the dual problem as $\min_{\lambda,\nu} D(\lambda, \nu)$ subject to $\lambda, \nu \geq 0$ which can be minimized by means of gradient descent methods. The resulting dual problem minimizes the dual function $D(\lambda, \nu)$ in (9) w.r.t to dual variables λ, ν while at the same time maximizing the Lagrangian (8) w.r.t. primal variables a, x. The unique features of this dual problem, that is, the separability of Lagrangian over a, x and strong duality, lead us to the implementation of iterative and distributed algorithms which only require the exchange of *prices* (Lagrange multipliers) between links, cliques and peers to reach the global optimum. The distributed nature of these algorithms enables the RPS algorithm to easily scale with the number of peers, size of the network and the number of P2P overlays. Although the algorithm is considered in the context of wireless networks, the RPS algorithm can easily be converted for wired or hybrid network scenarios, by fixing $a_l = 1$ and $\nu_l = 0$ for all wired links, removing all wired links from conflict graph and then conducting the same RPS algorithm.

The proposed distributed and iterative algorithm for calculation of dual (λ,ν) and primal (a,x) parameters are summarized in Table I. The algorithm is composed of receiver and link parts which run independently on each receiver and link in the network by exchanging information. The link algorithm corresponds to the functionalities in the underlay network, where receiver part relates to the optimization of the ovelay network. In steps R0 and L0 of Table I, optimization parameters are first initialized. Then in Step L1, links iterate the solution of dual problem over congestion price λ by using gradient methods $\lambda(t+1) = \lambda(t) - \beta_\lambda \nabla_\lambda D(\lambda, \nu)$ as given in (11). Step L2 refers to the MAC optimization procedure which is given in detail in [13]. Hence, MAC layer contention price ν, which minimizes the dual function in (9) and the successful medium access probability a which maximizes the Lagrangian in (8) are calculated as given in (12). For the sake of completeness we note that contention prices are calculated per max. clique by using a simple gradient descent algorithm and individual link access probabilities a_l are approximately calculated by maximizing the partial lagrangian as $\max_{a_l}\ \lambda_l a_l c_l - \sum_{n \in \mathcal{F}} \nu_n f_{nl} a_l$ for $0 \leq a_l \leq 1$ after adding a small quadratic term $-\sum_l a_l^2 \delta_a$.

By now, the dual parameters λ, ν and the primal parameter a are all calculated by the distributed link algorithms. Meanwhile, in Step R1 of receiver algorithm, each P2P receiver calculates the rates allocated to the source peers $x^{(k)} = [x_{k1} \ldots x_{kS_k}]$ by solving the subproblem (10) that incorporates the congestion prices λ obtained from the associating links. The process repeats until convergence of peer-to-peer flow rates and the congestion prices. And at the end, x_{ks} parameters determine the selected peers and corresponding rates for newly joining peer k where at the same time MAC layer optimization algorithm optimizes MAC layer channel access parameters, a_l.

IV. SIMULATION AND DISCUSSION

We use the simple ad hoc wireless multi-hop network topology in Figure. 1 to illustrate the performance of the proposed RPS algorithm. Although we only consider the simple case of a single P2P receiver, it should be noted that the proposed RPS algorithm is fully distributed and scalable. The given topology is composed of $L = 9$ links, $M = 9$ max. cliques and three unicast flows (AH, DC, FG) (i.e. $S_k = 1$). A newly joining P2P receiver at G runs RPS algorithm for different number of source peers, where $S_k \geq 1$. Both unicast and P2P congestion control is conducted on the basis of proportional fairness as given in (7) for $\alpha = 1$. Bear in mind that the aim of our paper is not to propose a protocol for non-P2P unicast flows. We therefore choose the scheme described in [12] for the co-existing unicast traffic. It was shown that standard TCP/IP transport together with AQM (Active Queue Management) can distributedly optimizes a similar NUM problem. Hence, not surprisingly, the equation (10) in RPS algorithm gives the same solution with [12] if we set $S_k = 1$, remove the bandwidth limitation $b_s^{(k)}$ and drop the index k in (i.e. $x_{ks} \rightarrow x_s$).

In all simulations we set the video rate of source peers available to receiver k as $\{b_H^{(k)}, b_F^{(k)}, b_E^{(k)}, b_D^{(k)}, b_C^{(k)}, b_B^{(k)}, b_A^{(k)}\} = \{25, 50, 100, 200, 350, 550, 800\}$ kbps. The total number of S_k available source peers for receiver k are always selected as a partially ordered set from this list. In Fig. 3, as the number of available source peers are varied from 1 to 7, the source peer set $\mathcal{S}(k)$ for receiver k is picked up randomly in the ascending video bit rate order as $\{H\}$, $\{H, F\}$, ... , $\{H, F, E, D, C, B, A\}$ by excluding the node $k = G$ on which

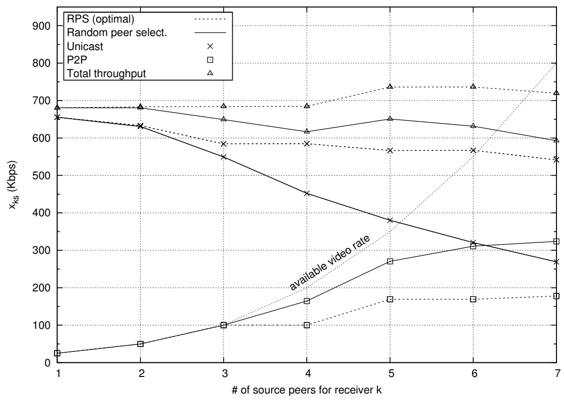

Fig. 3. Unicast, P2P and total throughput for RPS and random peer selection

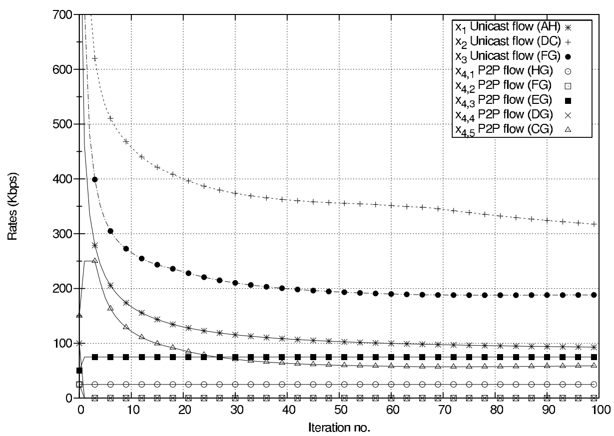

Fig. 4. Convergence of rate allocation for unicast and P2P traffic

the RPS algorithm runs. In Figure 3 for the increasing number of peers, the results of optimal peer selection algorithm RPS for newly joining peer G is compared with the random peer selection. Results of random peer selection algorithm is shown with solid lines. It is easily observable that, with increasing number of peers the throughput of the underlay network decreases and unicast sources are suppressed. On the contrary, the RPS algorithm enables the network to maintain a high throughput and even increase when the number of source peers increase. Suppression on the co-existing unicast flows in this case is minor. The increase in network throughput can be expected since as the number of peers increase, the receiver will have the chance to select better receiver to source paths.

We also present the behaviour of the optimization parameters of RPS algorithm. In this setup, for P2P receiver k at node G, we set the number of available P2P sources to $S_k = 5$ which results in $\mathcal{S}(k) = \{H, F, E, D, C\}$. Results are shown in Fig. 4 and it illustrates how the P2P and unicast flow rates x_{ks} and x_s are converging to the optimal values. From this figure we can see that less rate is assigned to paths with higher cost in unicast flows (i.e. high cost can be interpreted as longer paths or more congested links). Furthermore, bandwidth limitations due to available FGS video rates are visible where rates on HG and EG cannot exceed the video rate limits $b_H^{(k)}$ and $b_E^{(k)}$ respectively for $k = G$. And at the end selected peers by $k = G$ is observed as C, E, H with corresponding rates x_{ks}. The requested rates are allocated by the receiver with a coordinated decision that makes use of the congestion information on each path. The algorithm always prefers peers with the least congestion in order to maximize the utility of the network. We also observed that the resulting channel access probabilities found by the MAC layer optimization algorithm give the more congested links a higher channel access time.

V. Conclusions and Future Work

In this paper, we formulate the joint peer selection and rate allocation problem (including MAC layer optimization) for multimedia streaming in P2P overlay networks through a network utility optimization framework. We then constructed a distributed algorithm, RPS, by using dual decomposition. Simulation results show that by using the proper price exchange mechanism, the peer receivers can distributedly maximize the throughput of the underlay network by an intelligent peer selection algorithm without any need for centralized resource planning and utilization of tree topologies for content distribution.

An immediate step in future work is to evaluate how the proposed scheme will perform in an actual network setting. Furthermore, P2P upload/download fairness and source-to-receiver delay issues may be integrated into the optimization framework as a possible future step.

References

[1] V. Padmanabhan et. al., “Distributing streaming media content using cooperative networking,” in *Proceedings of NOSSDAV*, Miami, FL, 2002.

[2] D. Kostić; A. Rodriguez; J. ALbrecht and A. Vahdat, “Bullet: high bandwidth data dissemination using an overlay mesh,” in *Proceedings of ACM Symposium on Operating Systems Principles*, 2003.

[3] T. Small; B. Li and B. Liang, “Outreach: peer-to-peer topology construction towards minimized server bandwidth costs,” *IEEE Journal on Sel. Areas in Communications*, vol. 25, no. 1, pp. 35–45, Jan 2007.

[4] X. Zhang; J. Liu; B. Li and T. P. Yum, “Coolstreaming/donet: A data driven overlay network for efficient live media streaming,” in *Proc. of IEEE INFOCOM*, Miami, FL, 2005.

[5] V. Venkatraman et. al., “Chuckyspread overlay multicast,” in *Proc. of 2nd Symp. on Networked Systems Design and Implementation*, 2005.

[6] D. Astuti and M. Kojo, “Evaluating the behaviour of peer-to-peer IP traffic in wireless access networks,” in *Proc. of International Network Conference*, Samos, Greece, 2005.

[7] A. K-H. Leung and Y-K Kwok, “On topology control of wireless peer-to-peer file sharing networks: Energy efficiency, fairness and incentives,” in *Proc. of IEEE WoWMoM*, Taormina, Italy, 2005.

[8] B. Yang and H. Garcia-Molina, “Designing a super peer network,” in *Proceedings of International Conference on Data Engineering*, 2003.

[9] A. M. Mahdy; J.S. Deogun; J. Wung, “Mobile ad hoc networks: a hybrid approach for the selection of super peers,” in *Proc. of International Conference on Wireless and Optical Commumnication Networks*, 2005.

[10] M. Chiang et. al., “Layering as optimization decomposition: A mathematical theory of network architectures,” *Proceedings of the IEEE*, vol. 85, no. 1, pp. 255–312, Jan. 2007.

[11] W. Li, “Overview of the fine granularity scalability in MPEG-4 video standard,” *IEEE Transactions on Circuits and Systems for Video Technology*, vol. 11, no. 3, pp. 301–317, Mar 2001.

[12] S. H. Low and D. E. Lapsley, “Optimization flow control — I: basic algorithm and convergence,” *IEEE/ACM Transactions on Networking*, vol. 7, no. 6, pp. 861–874, Dec. 1999.

[13] E. Gurses and A. N. Kim, “Utility optimal real-time multimedia communication in wireless mesh networks,” 16th International Packet Video Workshop, Lausanne, Switzerland, Nov. 2007.