This full text paper was peer reviewed at the direction of IEEE Communications Society subject matter experts for publication in the IEEE Globecom 2010 proceedings.

Favorable Peer Supported Throughput Optimization in Wireless Mesh Network

Mohammad Zulhasnine
Systems and Computer Engineering
Carleton University, Ottawa, Canada
Email: mzulhasn@sce.carleton.ca

Changcheng Huang
Systems and Computer Engineering
Carleton University, Ottawa, Canada
Email: huang@sce.carleton.ca

Anand Srinivasan
EION Inc.
Ottawa, Canada
Email: anand@eion.com

***Abstract*—Peer selection strategy is one of the major challenges towards efficient peer-to-peer (P2P) system in wireless mesh networks (WMNs). When peers choose their own utility-maximizing strategies for coalition and peer formation, the solution is always sub-optimal. Peer formation, based on only application layer information, also results in inefficient use of network bandwidth. When multiple *recipient-peers* try to access the same file from same *source-peer* simultaneously, contention may occur on the shared wireless channel. On the discovery of multiple *source-peers*, corresponding *recipient-peer* may choose optimal *source-peer* in favor of increased network throughput. Here, we propose a novel optimization method to calculate the upper bound of the aggregate throughput for P2P over WMNs utilizing the underlying physical network information and optimal peer selection strategy. The results show that our favorable-peer selection strategy, results in higher aggregate throughput by selecting optimum *source-peers* with better load distribution and minimum interference.**

I. Introduction

WMN is an emerging technology to provide broadband and scalable access to fixed and mobile applications across metropolitan areas. Unlike mobile ad hoc networks (MANETs), where mobility and power consumption pose major challenges; throughput and fairness are the most critical concerns in WMNs. Several cross-layer designs have been proposed in an attempt to maximize the achievable aggregate throughput. The work in [1], proposed a cross-layer design for joint routing and resource allocation of the physical (PHY) and the medium access control (MAC) layers in WMNs. The paper in [2], addressed the joint end-to-end rate optimization and radio resource management problem in wireless orthogonal frequency division multiplexing (OFDMA)-based mesh networks. The optimal network operation is defined in terms of a utility maximization problem subject to link capacity constraints, power and rate control and time-frequency assignment. In [3], the authors implemented optimization method to calculate network throughput with joint rate control, routing and scheduling in a WMN. However, the scheme requires to identify all possible transmission modes in the first step.

P2P over WMNs has received significant attention [4], [5]; a combination of both offers new possibilities, but poses several challenges as well. P2P searching protocol, which relies on overlay network, yields some penalties in terms of bandwidth usage due to a partial removal of routing intelligence of the network layers. The authors in [4] proposed an efficient algorithm for wireless P2P file sharing systems with the assumptions of having full awareness of the underground network topologies. However, this paper did not mention about resource allocation procedure. [5] also proposed a network-aware P2P file architecture. This scheme assigns the peers to a network-aware cluster using a network prefix division and thereby enables the files to be searched first with nearby peers. Recently, locality-based peer selection paradigm has gained considerable interest [6], [7]. The authors in [6], suggested that Internet service providers (ISPs) and P2P service provider can collaborate in order to conserve bandwidth resources consumed by P2P applications. [8] proposed a cross-layering approach between location-awareness and MAC layer to improve the efficiency of P2P system over WMN. The authors assumed that the location-aware ID are implemented from peers' location-awareness possibly using the GPS receivers.

We want to evaluate the maximum throughput of a P2P file sharing system and thereby identify the factors and their influences on aggregate throughput. We denote a node that wants to retrieve a file as *recipient-peer*. We assume that each *recipient-peer* initiates a peer discovery mechanism to find potential *source-peers.* Any *recipient-peer* may find multiple *source-peers* which yield multiple paths routed from these sources to *recipient-peers*. Other *recipient-peers* may seek same file segments and eventually discover same *source-peer(s)*. However, when multiple *recipient-peers* try to access same *source-peer* simultaneously, contention may occur on the shared wireless channel. Similarly, contention may also occur when multiple *recipient-peers* try to access different content from one *source-peer* simultaneously. Forming peers based on greedy algorithm will always give suboptimal solution. It is possible to improve the overall P2P network in terms of bandwidth utilization and delay minimization through selecting favorable peer employing optimization technique with Network/Application layer information.

We do not make an attempt to propose any new protocol for a P2P file system over WMNs as [4], [5], [8]; rather emphasize on calculating upper bound of the network resource to identify the factors that influences the aggregate throughput. Opposed to previous approaches [1], [2], [3], where optimization is implemented to maximize utility for multiple sources and multiple fixed destinations; we consider selecting optimum destinations in favors of maximizing the utility. To the best of our knowledge, we are the first to consider selecting optimum destinations to calculate the upper bound of the aggregate throughput using network-wide optimization. This allows us to gain insight in the influence of routing schemes, and peer selection strategies on the network performance.

II. System Model

We consider a WMN with nodes located at fixed position. Each node consists of a transmitter, a receiver and an infinite buffer and can only receive data in the signal range of communicating nodes if its signal to interference and noise ratio (SINR) is higher than a specified level. We represent the topology of the network by a directed graph $\mathcal{G} = (\mathcal{N}, \mathcal{L})$, where $\mathcal{N} = 1, 2, \ldots, N$ and $\mathcal{L} = 1, 2, \ldots, L$ label all the nodes and links, respectively. Each link $l \in \mathcal{L}$ is represented by an ordered pair (u, v) of distinct nodes, where the presence of link (u, v) means that the network is able to send data from node u to node v.

We understand that a good increase in throughput can be achieved by employing adaptive transmission rates and variable transmit powers, However, our prime goal is to determine the factors that influence aggregate throughput. To keep our problem formulation simple and not to divert from our main investigation, we only consider fixed transmission rates and transmit powers WMN. Transmitter of node u either transmits power P_u or remains silent. G_{uv} denotes the effective power gain between the transmitter of node u and the receiver of node v and is measured by the deterministic fading model, $G_{uv} = K_{uv} d_{uv}^{-\xi}$. Here, d_{uv} is the distance between transmitter u and receiver v, ξ is a constant path loss exponent and K_{uv} is a normalization constant. The normalization constant depends on the radio propagation properties of the environment, and also accounts for the effects of coding gain, spreading gain, beamforming, etc. Also, note that $G_{uu} = 0$. We define thermal noise power at receiver of node u as σ_u. Then the SINR at receiver of node v is

$$\gamma_{uv} = \frac{G_{uv} P_u}{\sigma_v + \sum_{k \in \mathcal{N}, k \neq u} G_{kv} P_k} \tag{1}$$

The capacity of link l of the ordered pair (u, v) is determined by the Shannon capacity model

$$c_l = W \log_2(1 + \gamma_{uv}) \tag{2}$$

where W is the system bandwidth. In our model, we assume that a transmitter of node u only transmits to the receiver of node v if γ_{uv} exceeds target SINR value of γ_l^{tgt}. And the transmission rate with this γ_l^{tgt} is obtained as

$$c_l^{tgt} = W \log_2(1 + \gamma_l^{tgt}) \tag{3}$$

We assume a scheduling-based MAC layer where each scheduling period takes '1' unit time. A scheduling period is further divided into multiple transmission modes. On each transmission mode, multiple non-interfering links may transmit at the same time for a fraction of the unit scheduling period. We use $\mathcal{T} = 1, 2, \ldots, T$ to represent the set of transmission mode. T is sufficiently large $(T > L)$ such that all links get opportunity to transmit for at least once. On each transmission mode, a transmitter of node u can only transmit to the receiver of node v if $\gamma_{uv} \geq \gamma_l^{tgt}$. We do not need to generate $\mathcal{T}$ as it is obtained from the results of our network-wide optimization model.

III. Problem Formulation

We formulate the problem of favorable peer selection and topology awareness as a mixed integer linear programming (MILP) while achieving system level performance both in terms of throughput and fairness. To capture the effect of routing scheme on throughput, we consider both fixed and flexible routing. We label the *recipient-peers* by integers $p = 1, 2, \ldots, P$. For any peer p, number of possible *source-peers* is Q^p and is defined by the set $\mathcal{Q}^p = \{1, 2, \ldots, Q^p\}$. Hence, the total number of *source-peers*, $Q = \sum_p Q^p$. Let s_p^q denotes the end-to-end rate for communication between *recipient-peer* p and *source-peer* q with $q \in \mathcal{Q}^p$. For each peer p, $\hat{s}_p$ denotes the optimum rate towards the optimum *source-peer* $q \in \mathcal{Q}^p$. Our aim is to estimate the maximum throughput for the following criteria:

***Criteria 1* (MRA):** The *Maximum Throughput Rate Allocation* optimizes the E2E rate of the peers through selecting favorable peer such that $\sum_p \hat{s}_p$ is maximized. This method does not consider the fairness issue.

***Criteria 2* (MMRA):** The *Maximum of Minimum Throughput Rate Allocation* optimizes the E2E rate of the peers through selecting favorable peer such that τ is maximized with $\tau \leq \hat{s}_p$ for each peer p. Here, τ is the E2E rate smaller or equal to $\min(\hat{s}_p; \quad p \in P)$. In this method E2E rates are made as equal as possible to the smallest E2E rate providing meaningful fairness.

***Criteria 3* (MGMRA):** The *Minimum Guaranteed Maximum Throughput Rate Allocation* optimizes the E2E rate of the peers through selecting favorable peer such that $\sum_p \hat{s}_p$ is maximized provided $\hat{s}_p \geq s_p^{min}$ for each peer p. s_p^{min} is minimum E2E rate of peer p. This method ensures some degree of fairness avoiding starvation to any peer.

A. Throughput bound with fixed routing

In case of fixed routing scheme, we assume that each *recipient-peer* initiates a peer discovery mechanism and eventually may discover multiple potential *source-peers.* For each peer p, we define a link layer route matrix $\mathcal{R}^p \in \mathbb{R}_{L \times Q_p}$. The entries r_{lq}^p of $\mathcal{R}^p$ satisfy $r_{lq}^p = 1$, if *recipient-peer* p has an end-to-end (E2E) path at q-th source through link l; otherwise 0. Let y_t^l represents a binary variable which satisfies $y_t^l = 1$ if link l is active on transmission mode t; 0 otherwise. We summarized the MILP formulation for MRA, MMRA, and MGMRA as the following:

MILP1: MRA

$$Maximize \qquad \sum_p \sum_q^{\mathcal{Q}^p} s_p^q \tag{4}$$

subject to:

$$s_p^q \geq 0, \quad \forall p, q \in \mathcal{Q}^p \tag{5}$$

$$s_p^q \leq \mathcal{M} w_p^q, \quad \forall p, q \in \mathcal{Q}^p \tag{6}$$

$$\sum_q^{\mathcal{Q}^p} w_p^q = 1, \quad \forall p \tag{7}$$

$$\sum_p \sum_{q \in \mathcal{Q}^p} r_{lq}^p s_p^q \leq \sum_{t=1}^{T} \alpha_t c_l^{tgt} y_t^l, \quad \forall l \in \mathcal{L} \tag{8}$$

$$\sum_{t=1}^{T} \alpha_t = 1, \quad \alpha_t \geq 0, \quad \forall t \in \mathcal{T} \tag{9}$$

$$G_{uv} P_u y_t^l + \mathcal{M}(1 - y_t^l) \geq$$

$$\gamma_l^{tgt} \left(\sigma_v + \sum_{k \in \mathcal{N}, k \neq u} G_{kv} P_k \sum_{l \in \mathcal{L}^k} y_t^l \right), \quad \forall t \in \mathcal{T}, l \in \mathcal{L} \tag{10}$$

$$\sum_{l \in \mathcal{L}^v} y_t^l \leq 1, \forall t \in \mathcal{T}, v \in \mathcal{N} \tag{11}$$

Here, $\mathcal{M}$ is a constant of large value. w_p^q is a binary variable in constraints (6) and (7), which forces all s_p^q to be '0' except '1' for each p, and $q \in \mathcal{Q}^p$. Hence, only one *source-peer* is selected for each *recipient-peer*. The scalars α_t represent the fraction of unit time that transmission mode t is activated. For our scheduling-based MAC layer, the average transmission rate of link l is $\sum_{t=1}^{T} \alpha_t c_l^{tgt} y_t^l$ when constraint in (9) implies. The constraints in (8) guarantees the total traffic across the link l should be less than the average transmission rate of that link. Constraint in (10) imposes that link l is not active if the SINR of the receiver is less than γ_l^{tgt}. Defining $\mathcal{L}^u \subseteq \mathcal{L}$ links at node u, constraint in (11) imposes that transmitter/receiver at each node u transmits/receives data from only one transmitter at time fraction t.

Linearization: The part of expression $\alpha_t c_l^{tgt} y_t^l$ in (8) is a multiplication of a continuous variable (α_t) and a binary variable (y_t^l). We introduce another variable z_t^l to linearize the constrain in (8) as defined by

$$z_t^l = \alpha_t y_t^l \quad \forall l \in \mathcal{L}, t \in T \tag{12}$$

The constraints in (13), (14), (15) imply on z_t^l.

$$z_t^l \leq \alpha_t^{ub} y_t^l, \quad \forall t \in \mathcal{T}, l \in \mathcal{L} \tag{13}$$

$$z_t^l \leq \alpha_t - \alpha_t^{lb}(1 - y_t^l), \quad \forall t \in \mathcal{T}, l \in \mathcal{L} \tag{14}$$

$$z_t^l \geq \alpha_t - \alpha_t^{ub}(1 - y_t^l), \quad \forall t \in \mathcal{T}, l \in \mathcal{L} \tag{15}$$

where, α_t^{lb} and α_t^{ub} denote the lower and upper bound of α_t.

$$\sum_p \sum_{q \in \mathcal{Q}^p} r_{lq}^p s_p^q \leq \sum_{t=1}^{T} c_l^{tgt} z_t^l, \quad \forall l \in \mathcal{L} \tag{16}$$

$$z_t^l \leq y_t^l, \quad \forall t \in \mathcal{T}, l \in \mathcal{L} \tag{17}$$

$$z_t^l \leq \alpha_t, \quad \forall t \in \mathcal{T}, l \in \mathcal{L} \tag{18}$$

$$z_t^l \geq \alpha_t + y_t^l - 1, \quad \forall t \in \mathcal{T}, l \in \mathcal{L} \tag{19}$$

Constraints in (17), (18), (19) are obtained from constraints in (13), (14), (15), respectively as $\alpha_t^{lb} = 0$ and $\alpha_t^{ub} = 1$. In order to linearize the formulation, we replace the constraint in (8) with the constraint in (16) along with constraints in (17)-(19). The number of variables grows on the order of $\mathcal{O}(2 * L * T + 2 * Q + T)$ and the number of constraints grows on the order of $\mathcal{O}(5 * L * T + Q + 2 * P + L + 1)$.

MILP2: MMRA

$$Maximize \qquad \tau \tag{20}$$

subject to: Constraints (5)-(7), (9)-(11), (16)-(19), (21)

$$\tau \leq \sum_{q \in \mathcal{Q}^p} s_p^q, \quad \forall p \tag{21}$$

The number of variables grows grows on the order of $\mathcal{O}(2 * L * T + 2 * Q + T + 1)$ and the number of constraints grows on the order of $\mathcal{O}(5 * L * T + Q + 3 * P + L + 1)$.

MILP3: MGMRA

$$Maximize \qquad \sum_p \sum_q^{\mathcal{Q}^p} s_p^q \tag{22}$$

subject to: Constraints (5)-(7), (9)-(11), (16)-(19), (23)

$$\sum_q^{\mathcal{Q}^p} s_p^q \geq s_p^{min}, \quad \forall p \tag{23}$$

The number of variables grows on the order of $\mathcal{O}(2 * L * T + 2 * Q + T)$ and the number of constraints grows on the order of $\mathcal{O}(5 * L * T + Q + 3 * P + L + 1)$.

B. Throughput bound with flexible routing

We use the term "flex routing" for the load balance routing in favor of increased E2E rates. To incorporate flexible routing in favor of higher throughput we extend formulation with the following constraint:

$$\sum_{l \in \mathcal{L}_{\mathcal{O}}^u} {}_l x_p^q - \sum_{l \in \mathcal{L}_{\mathcal{I}}^u} {}_l x_p^q = \begin{cases} s_p^q & \text{if } u \text{ is a } \textit{source-peer}, \\ -s_p^q & \text{if } u \text{ is a } \textit{recipient-peer}, \\ 0 & \text{otherwise}, \end{cases}$$
$$\forall u \in \mathcal{N}, l \in \mathcal{L} \tag{24}$$

and also replace the constraint in (16) with the constraint in (25).

$$\sum_p \sum_q^{\mathcal{Q}^p} {}_l x_p^q \leq \sum_{t=1}^{T} c_l^{tgt} z_t^l, \quad \forall l \in \mathcal{L} \tag{25}$$

Here, ${}_l x_p^q$ denotes the amount of traffic on link l from the *source-peer* $q \in Q^p$ to the *recipient-peer* p. $\mathcal{L}_{\mathcal{O}}^u$ and $\mathcal{L}_{\mathcal{I}}^u$ denote the outgoing and incoming links at node u, respectively. Constraints in (24) ensures the flow conservation law. For any node other than source and destination, the amount of ingoing flow is equal to the amount of outgoing flow. Also, the net flow leaving at the source and entering at destination is equal to the source rate. Constraint in (25) guarantees that the total amount of traffic on link l, $\sum_p \sum_q^{Q^p} {}_l x_p^q$ does not exceed the link capacity c_l. The number of variables increases on the order of $\mathcal{O}(L * Q)$ and the number of constraints increases on the order of $\mathcal{O}(N * L)$.

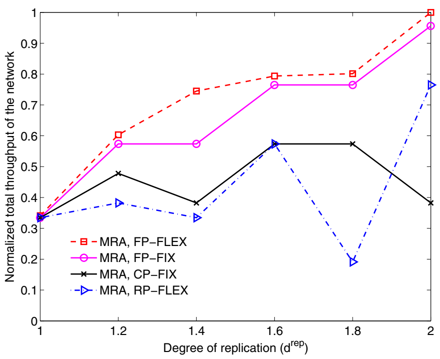

Fig. 1. Normalized aggregate throughput in terms of degree of replication for MRA criteria.

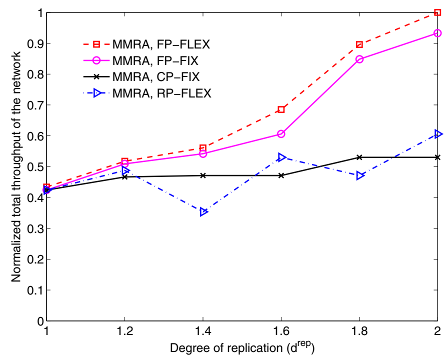

Fig. 2. Normalized aggregate throughput in terms of degree of replication for MMRA criteria.

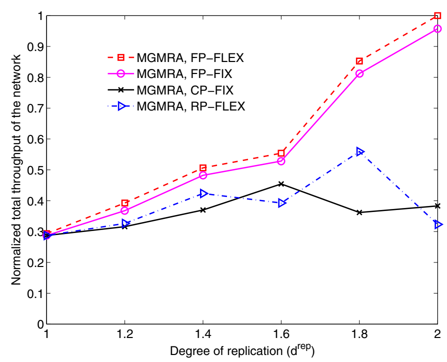

Fig. 3. Normalized aggregate throughput in terms of degree of replication for MGMRA criteria.

IV. Solution Techniques and Results

In order to solve the MILP formulation, we develop a program using C++ and incorporate the free optimization software, *lp_solve* version 5.5 [9]. We implement our optimization model on 10 different WMNs with n nodes randomly located in a $200 \times 200m^2$ region. We evaluate the industrial, scientific and medical (ISM) frequency band $2.4000 - 2.4835$ GHz as described in [2]. The path loss exponent $\xi = 3$, the normalization constant $K_{uv} = 2 \times 10^{-4}$, the power of each transmitter $P = 100mW$, and the thermal noise at each receiver $\sigma = 3.34 \times 10^{-12}$. We use these parameters to generate the links. With $\gamma_l^{tgt} = 10$ for all $l \in \mathcal{L}$ and $W = 83.5$ MHz, a link exists if $d_{uv} \leq 85.4m$ with 288.9 $Mbps$ capacity. Although we perform our simulation on several networks, we present results for only mid-size network consisting $n = 10$ nodes and $L = 36$ links due to space limitation and similar pattern in the results.

A. The influence of peer selection strategy

We name the optimal peer obtained from MILP formulation as *favorable-peer*. Here, we compare our favorable peer selection approach with two other existing peer selection strategies: random peer and closest peer. At first we show the results that shows the efficacy of *favorable-peer* selection strategy over two other strategies *random-peer* and *closest-peer* in terms of aggregate throughput. The *closest-peer* selection strategy is necessarily based on the shortest-path route algorithm. We implement the *favorable-peer* strategies for both fixed routing (shortest-path), and flexible routing and mark them as FP-FIX and FP-FLEX, respectively. We also tag *random-peer* and *closest-peer* selection scheme as RP-FLEX and CP-FIX, respectively. We consider aggregate throughput of the network as our key metric. We define the degree of replication, d^{rep} as the ratio of *source peers* over *recipient-peers*. For an example, consider $P = 4$. If the number of *source-peers(s)* for *recipient-peer 1, 2, 3* and *4* are 2, 1, 3 and 1; then $d^{rep} = (2 + 1 + 3 + 1)/(4) = 1.75$.

***Criteria* 1 (MRA):** Fig. 1 depicts the normalized aggregate throughput in terms of degree of replication for MRA problem. With MRA, both FP-FLEX and FP-FIX peer selection methods show increased normalized aggregate throughput with the increase in degree of replication. FP-FLEX and FP-FIX peer selection methods also perform better in terms aggregate throughput than that of CP-FIX and RP-FLEX peer selection methods. For example, with $d^{rep} = 1.0$, there is no significant difference in aggregate throughput for all peer selection strategies with the absence of multiple *source-peers* for any *recipient-peer*. And with $d^{rep} = 1.8$, the aggregate throughput in FP-FIX peer selection strategy is 74% and 26% higher than that of CP-FIX and RP-FLEX selection strategy, respectively. Moreover, with $d^{rep} = 1.8$, FP-FLEX selection strategy exhibits 4% higher throughput than that of FP-FIX peer selection strategy. This is due to the fact that *favorable-peer* selection methods, select *source-peers* with the least-interference paths.

***Criteria* 2 (MMRA):** Fig. 2 illustrates the normalized aggregate throughput in terms of degree of replication for MMRA problem. Like MRA problem, FP-FLEX and FP-FIX peer selection methods perform better in terms aggregate throughput than that of CP-FIX and RP-FLEX peer selection methods. For example, with $d^{rep} = 1.4$, the aggregate throughput for FP-FIX selection strategy is 35% and 13% higher than that of CP-FIX and RP-FLEX peer selection methods, respectively. Moreover, as expected, FP-FLEX peer selection method outperforms FP-FIX peer selection method.

***Criteria* 3 (MGMRA):** Fig. 3 shows the normalized aggre-

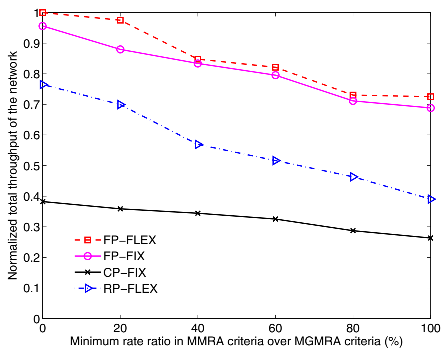

Fig. 4. Normalized aggregate throughput in terms of minimum rate ratio in case of MMRA criteria over MGMRA criteria.

gate throughput in terms of degree of replication for MGMRA problem. As expected, with FP-FLEX and FP-FIX peer selection methods, the normalized aggregate throughput increases with the increase in degree of replication. With $d^{rep} = 1.4$, the aggregate throughput for FP-FIX selection strategy is 12% and 23% higher than that of RP-FLEX and CP-FIX peer selection strategies, respectively. Hence, for all criteria (MRA, MMRA and MGMRA), the aggregate throughput increases with increase in the degree of replication for FP-FLEX and FP-FIX peer selection methods. The normalized aggregate throughput varies randomly with RP-FLEX selection and CP-FIX peer selection strategies. Also, FP-FLEX and FP-FIX peer selection methods perform better in terms aggregate throughput than the *random-peer* and *closest-peer* selection strategies. This is due to the fact that when multiple *recipient-peers* try to access the same file from same *source peer* simultaneously, contention occurs on the shared wireless channel in case of *random-peer* and *closest-peer* selection strategy. Our *favorable-peer* selection strategy avoids this problem through judicial selection of *source-peers*. Moreover, in all cases, flex-routed *favorable-peer* method outperforms fixed-routed *favorable-peer* method.

B. Fairness and aggregate throughput

Here, we also investigate the effect of fairness constraints on the overall throughput of WMN. We denote s^{min}_{MMRA} and s^{min}_{MGMRA} as the minimum E2E rate among the E2E rates of all peers in MMRA and MGMRA criteria, respectively. Then $R^{min}_{E2E} = \frac{s^{min}_{MGMRA}}{s^{min}_{MMRA}} \times 100$ defines the minimum E2E rate ratio in MGMRA criteria over MMRA criteria in percentage. $R^{min}_{E2E} = 0\%$ indicates minimum E2E rate in MGMRA criteria is '0', this is eventually a MRA criteria without any fairness issue. $R^{min}_{E2E} = 100\%$ indicates minimum E2E rate in MGMRA criteria is equal to that of MMRA criteria; this is eventual a MMRA criteria where the highest degree of fairness achieved through an attempt to equalize all rates to the smallest.

Fig. 4 shows the relationship between fairness and aggregate throughput of the network. With $R^{min}_{E2E} = 0\%$ [$s^{min}_{MGMRA} = 0$, MRA criteria], the throughput is maximum for all peer selection strategies. Without fairness constraints, maximum network efficiency in terms of aggregate throughput is achieved at the expense of starvation of some peers. With $R^{min}_{E2E} = 100\%$ [$s^{min}_{MGMRA} = s^{min}_{MMRA}$, MMRA criteria], the throughput is minimum for all peer selection strategies at the expense of fairness. In MMRA problem, E2E of the peers are made as equal as possible to the smallest E2E rate providing highest degree of fairness. With the increase of R^{min}_{E2E}, aggregate throughput decreases from highest value (MRA criteria) to the lowest value (MMRA criteria). This is due to the fact that MGMRA allocates higher E2E rate for peers with better channel condition while maintaining minimum E2E for all peers. This method ensures some degree of fairness avoiding starvation to any peer provided $s^{min}_{MGMRA} \leq s^{min}_{MMRA}$. Hence, there exists a trade-off between the total throughput of the network and fairness in WMNs.

V. Conclusion

We have formulated the problem of favorable peer selection and topology awareness as a MILP to quantified the upper bound of the aggregate throughput of a P2P system over WMNs. The results provides an understanding of the determining factors behind network performance such as the degree of matching between the P2P overlay and its underlying physical network, the effective routing scheme, and nonetheless optimal peer selection. With favorable-peer selection strategy, network-wide load-distribution and minimum interference are achieved even with smaller degree of replication. Specially, when any recipient-peer discovers multiple source-peers, throughput can be increased dramatically upon intelligent selection of peers among the source-peers. We also have shown that there exists a critical relationship between the fairness and the achievable aggregate throughput of the the network. Designing distributed P2P protocol in WMNs that captures this notion is our ongoing future work.

References

[1] S.-J. Kim, X. Wang, and M. Madihian, "Cross-layer design of wireless multihop backhaul networks with multiantenna beamforming," *IEEE Trans. Mobile Comput.*, vol. 6, no. 11, pp. 1259–1269, Nov. 2007.

[2] P. Soldati and M. Johansson, "Network-wide resource optimization of wireless OFDMA mesh networks with multiple radios," in *IEEE International Conference on Communications (ICC)*, 2007, pp. 4979–4984.

[3] J. Tang, G. Xue, and W. Zhang, "Cross-layer design for End-to-End throughput and fairness enhancement in multi-channel wireless mesh networks," *IEEE Trans. Wireless Commun.*, vol. 6, no. 10, pp. 3482–3486, Oct. 2007.

[4] J. Li, L. Huang, W. Jia, M. Xiao, and P. Du, "An efficient implementation of file sharing systems on the basis of WiMAX and Wi-Fi," in *Proc. IEEE International Conference on Mobile Adhoc and Sensor Systems*, Oct. 2006, pp. 819–824.

[5] C.-M. Huang, T.-H. Hsu, and M.-F. Hsu, "Network-aware P2P file sharing over the wireless mobile networks," *IEEE J. Sel. Areas Commun.*, vol. 25, no. 1, pp. 204–210, Jan. 2007.

[6] H. Xie, Y. R. Yang, A. Krishnamurthy, Y. G. Liu, and A. Silberschatz, "P4P: provider portal for applications," in *ACM SIGCOMM Comput. Commun. Rev.*, 2008, pp. 351–362.

[7] V. Aggarwal, A. Feldmann, and C. Scheideler, "Can ISPs and P2P users cooperate for improved performance?" *ACM SIGCOMM Computer Commun. Rev.*, vol. 37, no. 3, July 2007.

[8] C. Canali, M. E. Renda, P. Santi, and S. Burresi, "Enabling efficient peer-to-peer resource sharing in wireless mesh networks," *IEEE Trans. Mobile Comput.*, vol. 9, no. 3, pp. 333–347, Mar. 2010.

[9] (2010) Free linear (integer) programming solver—lp_solve (version 5.5). [Online]. Available: http://lpsolve.sourceforge.net/