Cowtra: A COntribution Willingness-based Two-phase bandwidth Resource Allocation algorithm in P2P network

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Abstract*—Free-riding phenomenon is overwhelming in nowadays p2p network which causes researchers to investigate and develop many approaches to combat it. However, almost all the studies neglect the role of relative contribution of peers, namely willingness of contribution (WoC) in our paper. The ignorant to the ratio of peer's actually contribution to its physical capability would undoubtedly lead to unfairly resource allocation and discourage many peers, as well as loose their support in long term Therefore, in this paper we present a novel and effective approach Cowtra to address such problem. Our algorithm guarantees that the bandwidth of a source node is distributed properly according to the absolute contribution of the competing peers. Then we adjust the amount of competing peers' received bandwidth by utilizing the WoC in the second phase, such that peers with higher WoC obtain more resource while peers with lower WoC otherwise. At last, simulation results demonstrate the superiority of our algorithm in terms of fairness and efficiency.

Keywords-p2p;bandwidth allocation;fairness;free-rider

I. INTRODUCTION

P2P network consists of great masses of highly rational and autonomic peers. Rational peers hope to use more other provided resource than by offering own to realize self-maximization of interests. Therefore, if no proper incentives mechanism exists in the P2P network, the network will be packed with a large amount of selfish nodes, which act as "reaping without sowing". The common of tragedy [6,7] will happen so that the system may collapse. A proper and effective design of incentive resource allocation mechanism has already become a key issue for the health development and evolution of P2P network. Various of incentive mechanisms have been proposed in resource allocation and they can be classified mainly into two categories: Game-theory based [1,8,11] and Service Differentiation [5,9] based.

1. Game theory. Based on the peer self-interest and independent decision making characteristic, [1] adopts the design philosophy of the game theory to model peers interaction and the resource allocation process. In [8], the authors model nodes' activities as an infinitely repeated game in the P2P network where nodes get services based on their reputation. Although game theory is a good tool to analyze peer behavior and gives some suggestions to rational peer how to contribute, in reality, most game theory based resource allocation mechanism are based on complete information game, which is not practical in P2P networks where the globe information exchange is not realistic.

2. Service Differentiation. To differentiate users' service quality, the system needs to quantify and evaluate a peer's contribution/participation level, then take use of contribution level as the resource allocation criterion, in form of reputation, score, micro-payment and so on. However, these differential service resource allocation mechanisms neglect the fact that resource allocation mechanism only takes peer absolute contribution level into consideration is not enough and fair. The ignorant to the ratio of peer's actually contribution to its physical provision capability, namely Willingness of Contribution (WoC), would undoubtedly discourage many peers with high WoC for unfairly resource allocation. For instance, a peer staying on line for a long time is fully donating its upload bandwidth resource, but with comparatively poor physical capability which it cannot control, it can not get corresponding payoffs comparing to its enthusiastic contribution willingness, even worse, these good willingness peers would not participate in the p2p community in long term because of unfairly resource allocation.

And for another example, a high-performance peer, namely with large storage capacity, high uploading bandwidth, only needs to offer a small amount of physics abilities as contribution to obtain the same system resources as other normal peers in resource allocation. Therefore, some high ability peers with inherent selfish low contribution willingness can get a large number of resources from the network by utilizing their advantage in physical capability. Obviously, such consequence is not accordant with the principle of "high capacity ones take more responsibility" underlying in P2P network.

In this paper, we propose a novel and effective approach (Cowtra: A COntribution Willingness-based Two phase bandwidth Resource Allocation algorithm) which takes peer's WoC into consideration to address the bandwidth allocation unfairness problem. Also, we present a modified fairness metric CFI (Weighted Contribution-aware Fairness Index) of resource allocation to evaluate the resource allocation effectiveness.

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Simulations are conducted to evaluate the performance of the proposed bandwidth allocation mechanism. The results demonstrate that the proposed algorithm effectively differentiates the bandwidth quota received by competing peers in relative and absolute contribution perspective. At the meanwhile Cowtra maintains a good fairness and high overall system performance.

II. Related Work

In order to guarantee that the whole P2P community works in a healthy way that the bandwidth resource in P2P network should be allocated fairly and rationally. Consequently, in the past there have been several algorithms and mechanisms to study the resource allocation problem.

Ma, R.T.B [1] first proposes to treat the bandwidth resource allocation as a non-cooperation game; the bandwidth is distributed among the competing peers according to the peer competitive bidding and contribution. They stress that the bidding value be corresponding to itself contribution and a Nash Equilibrium is then obtained under this condition, in such scenario the ultimate allocation is almost determined by peers contribution. Although such method could achieve an optimum allocation theoretically, in reality competing peer is hard to determine its contribution level if it has no complete information about others when it submits the bandwidth request, thus it is difficult to realize in real P2P system.

Yonghe[2] considers a rank function which incorporates peer resource consuming and provision to evaluate how much bandwidth a peer can receive. The mechanism they proposed achieves max-min fairness, which maximizes the minimum social welfare obtained. A peer with bad ranking would be allocated fewer resources than the counterpart with good ranking. But although the resource allocation of bandwidth according to their comparative ranking rather than actually contribution is a progressive advancement, after all the coarse grain of the ranking can not successfully distinguish the difference level between nodes with high contribution and those with low contribution.

Eger [3] proposes two new trading schemes in bandwidth allocation process, which are based on pricing. One uses explicit price information while the other scheme uses the download rates from other peers as the price. For both distributed algorithms, though they can promote the cooperation of peers to various degrees; however, they fail to consider the crucial relations between the heterogeneous peer capability and relative contribution as other approaches. Therefore, the fairness of such allocation mechanism can not be guaranteed.

Recently, some researchers have noticed the important role of relative contribution in allocation mechanism, Yuhua Liu [4] has put forward the concept of relative contribution, and they utilize Analyses Hierarchy Process (AHP) model to weight each factor influencing the node relative contribution. An integrated utility function is constructed which takes the relative contribution into account. But their study did not put forward concrete resource allocation mechanism, mainly pay close attention to the modeling and computing of node relative contribution, which is the biggest difference between our work and theirs.

III. Premilirary Concepts

A. Bandwidth allocation Problem

We consider a scenario that a peer with fixed uploading bandwidth capacity has the desired service (e.g. file block, file content) attracting many competing peers. Such peer is referred to source node (SN). Meanwhile, we call other peers as competing node (CN) in that they are competing for the upload bandwidth of SN.

Without generality, in our model we consider only a single SN and N competing node. But it does not prevent nodes from requesting several source nodes simultaneously. Because in a multiple SNs scenario, SN can make allocation decision independently, the bandwidth allocation can be decomposed to several independent sub-problems. The multiple choices of SN and the strategies of how to distribute CN contribution to these SNs are out of discussion domain, so readers can refer to [5].

In a situation where the SN uploads bandwidth, which is a fixed one and denotes as W_s, Once the total demand from CN exceeds the SN capacity, then the SN needs a certain bandwidth allocation tactic, in order to offer more bandwidth to competing peers who have more contribution compared with those not contribute much. The tactic or the bandwidth strategy is what we focus on in this paper.

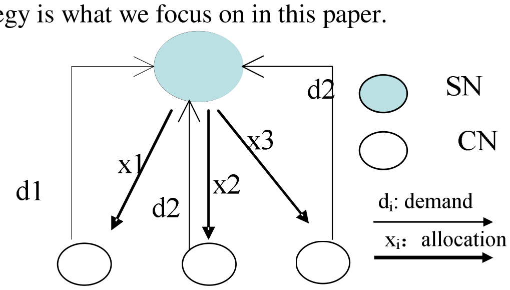

Figure 1. Source Node and Competing Nodes

B. Absolute contribution and Willingness of Contribution

We estimate a peer's contribution by focusing on the uploading bandwidth it provided to others. Notice that many other metrics can be utilized to overall judge a peer's participant level and contribution volumes, such as the number and size of files a peer has shared, the staying on line time and sharing file duration, etc. However, the contribution estimation and computation is not the major solving problem. Before we induce our Cowtra algorithms, we need to give some basic concepts and two important definitions: Absolute Contribution (AC) and Relative Contribution (RC, which is interchangeable with the term WoC if not confusing), as well as others.

Absolute Contribution: is the average statistic value of upload bandwidth for observing windows w. Formally, it expresses as :

$$\text{AbsCon}_{\text{i}} = \frac{1}{Win} \times \sum_{t=t_0}^{t=t_0+Win} Up_i(t) \qquad (1)$$

Willingness of Contribution: is the relative contribution of a peer. It is defined as the ratio of Absolution Contribution to the physical upload bandwidth, namely the maximum upload value. The physical capability (PCap) is not likely to change easily; at most time it is unchangeable. Therefore, the more a peer voluntarily contributes, the greater WoC it has.

$$WC_{\text{i}} = \frac{AbsCon_i}{PCap_i} = \frac{1}{Win \times PCap_i} \times \sum_{t=t_0}^{t=t_0+Win} Up_i(t) \qquad (2)$$

A major concern of the proposed approach is how to know peer physical capability precisely and prevent peers from cheating. We can use Trust-based [9] or Audit-base mechanism or secure bandwidth estimation approach such as EigenSpeed [10] to evaluate a peer's bandwidth.

Win: is the observing window size. It is defined to collect the peer's contribution behavior for the recent period. It can configured by the system designer according to the properties of application.

U_i (t): is the peer i's upload bandwidth at time t. it ranges from 0 to the maximum upload U_{max}.

$PCap_i$: is the peer i's physical capability in term of upload bandwidth, namely the U_i^{max}. The physical capability of a node is determined by peer internet connection type, ADSL, Cable, Ethernet etc.

IV. COWTRA OVERVIEW

In this section, we starts with the design of our COntribution Willingness-based Two-phase bandwidth allocation algorithm (Cowtra) which alleviates the unfairly resource allocation problem.

At the first phase of our mechanism, bandwidth of the SN is allocated according to the contribution of competing nodes by maximize the overall peer's utility, it does so in order to reduce, if does not get rid of, free-riding peers who want to pick up the resource without contributing to system. On this basis of preliminary allotment, SN immediately analysis the WoC of each competing nodes, a micro step-by-step adjustment would be conducted. Eventually, the allocation mechanism guarantees that peer with lower physical capability but has a large WoC is granted more resources than in the first allocation stage, yet peers choosing to act as low WoC would lose some resources for a punitive purpose. Therefore, a rational peer should choose to be more general and contribute more according to its physical capability.

A. *First phase: Contribution-Based Allocation.*

The intuition behind the first stage allocation design is simple. We want our allocation to be proportionally fair by the absolute contribution, that is to say, the competing node gets downloading rate from the SN in proportion to its own uploading bandwidth to the P2P community. Using as a reference from microeconomic theory, fairness can be achieved by two methods: either maximizing the all competing nodes utilities, namely the social welfare [1], or maximizing the minimum utility the peer obtained, that is max-min fairness [2]. All two methods are utilized prevalently in resource allocation context. We adopt the first one scheme for it is easy to implement and realize in real p2p network. We turn the resource allocation problem into a non-linear optimization problem as the work did [1].

Therefore, a peer with little contribution to system can only receive comparatively little resource. This character of first allocation phase makes rational peer to raise a bandwidth requirement in proportion with contribution.

B. *Second Phase: the Micro Adjustments*

On the basis of first phase allocation bandwidth, we proceed with the second stage: the micro adjustments. As to node with high WoC (the WoC is above average level to some extent), it receives a bit more as a reward to its high relative contribution, whereas to peer with lower Willingness of Contribution (WoC is below the average level to certain degree), we reduce the bandwidth resource it obtains as a mild punishment. What's more, the increment and decrement of bandwidth is differentiated according to the AC and RC. Before we come to explain how micro adjustment works, firsly, we classify the competing peers to four groups based on the relationship between AC and RC.

Group 1: It consists of peers with high AC as well as high RC. Since they have very high physics capability, also they contribute all or most ability out at the same time, these nodes make up of the main resource provider in P2P network, thence they are deserved to gain meritorious increment.

Group 2: Peers are willing to donate their resource yet constrained by the physical performance and capacity, they are nodes possess high RC and low AC. Therefore, these peers can receive certain compensation gains for their enthusiasm contribution behavior. But the increasing degree $\triangle_{12}$ is smaller than the first group peers. Because although they do one's utmost to contribute, the contributing amount is limited after all.

Group 3: Peers with large AC but small RC constitute the group 3. Although they have a large absolution contribution, yet they do not contribute to their corresponding capability. The powerful peers with high physical capability should be fully utilized to maximize the system capacity. Therefore, we reduce bandwidth obtained of peers in group 3 as a mild warning and punishment. Obviously, the decreasing degree $\triangledown_{21}$ is smaller than the fourth type peer. More over, the absolute contributing amount still can guarantee them to obtain certain payoffs and resource definitely.

Group 4: Peer who does not contribute much resource as well as being with little willingness to contribute is considered as the typical free-riders in P2P system. These pees neither do their best to donate resource despite of limited physical capacity, nor make a little absolute contribution at the same time. Undoubtedly, we would decrease their assigning amount of the bandwidth $\nabla 22$ at most.

The relation of the four groups in resource adjustment is depicted as Table 1. Four groups of node

1) The adjustment quantum determination

The adjustment quantum $\triangle$ and ∇ is an key issue in the active micro-adjustment, since it determines the adjustment speed and adjustment coverage speed. If the quantum is set too large, then it causes the volatile changes in bandwidth allocation, else if too small, it takes a long time to impose influence on the allocated bandwidth which is not effective. In our scheme we consider a proper and favorable quantum should satisfy the following properties: 1. At each iterative adjustment round, the quantum $\triangle$ and ∇ are both diminishing, for sufficient large step the quantum is approaching to zero. 2. At the same time, although the quantum is diminishing, the effect produced by aggregate adjustment quantum is influential to the allocation. Formally, two adjustment quantum sequences satisfying the above properties for $\triangle$ and ∇ respectively are descried as:

$\lim_{n\to\infty}\alpha_n = 0$, $\sum_{n=1}^{\infty}\alpha_n = \infty$ $\lim_{n\to\infty}\beta_n = 0$, $\sum_{n=1}^{\infty}\beta_n = \infty$, n denotes the adjustment round. Meanwhile, the allocated quantum sequence should be associated with the smallest amount of allocation, namely X_{min} in the first allocation phase, because we have to make sure the change range does not exceed the resource of amount a node has possessed. What's more, it should not cause deep effects to nodes with little allocation resource. Remember that the micro adjustment sequences satisfy : $\triangle_{11} > \nabla_{22} > \triangle_{12} > \nabla_{21}$. Therefore, in our active adjustment stage, we define the adjustment quantum as follows: $\triangle_{11} = \alpha_n \times x_{\min} > \nabla_{22} = \beta_n \times x_{\min} > \triangle_{12} = \frac{1}{2} \times \triangle_{11} > \nabla_{21} = \frac{1}{2} \times \nabla_{22}$ at each micro adjustment round.

The actually allocated bandwidth resource updated at each step is viewed as : $x_i^{t+1} = x_i^t + \triangle^t$, $\triangle^t \in \{\triangle_{11}, \nabla_{21}, \triangle_{12}, \nabla_{22}\}$,(t=1,2....) denotes the adjustment round.

Table 1. Four groups of node

Reltive Contribution	*RelCon large*		*RelCon small*	
Absolute Contribution	*AbsCon* large	*AbsCon small*	*AbsCon* large	*AbsCon* small
Node Group	The First group	The Sencond group	The Third group	The Forth group
Adjustment Range,Quantum	$\triangle_{11}$	$\triangle_{12}$	∇_{21}	∇_{22}
Adjustment Range Relations	$\triangle_{11} > \nabla_{22} > \triangle_{12} > \nabla_{21}$			

After the resource initial allocation finished in first phase, then we conduct the iterative micro resource adjustment process among the competing nodes. This adjustment process is consisted of two types: active way and passive way, and the adjustment process use the two ways sequentially for every round. The adjustment will not stop until the bandwidth allocation is fair enough or the adjustment quantity difference of two rounds is sufficient small.

During active adjustment, Cowtra assigns more resource or less resource to certain nodes deserved according to their RC and AC in an initiative way. If the active adjustment causes the deficit or surplus between the capacity of the SN and the total allocated bandwidth resource, then the difference bandwidth would be redistributed among the remaining nodes that are not evolved in active adjustment process. And such bandwidth allocation process is called passive adjustment. The concrete adjustment rules will be elaborated later.

2) Active Adjustment Stage

Firstly, for competing nodes set $\{N_1,N_2....N_n\}$, we rearrange them by the order of their Relative Contribution (also Willingness of Contribution) in a ascending way. They are denoted as N_{r_1} , N_{r_2} ... N_{r_n} , satisfying RelCon(N_{r_i}) ≤RelCon(N_{r_j}), for every sub index $r_i \le r_j$. RelCon($node_i$) is a function to get the relative contribution of $node_i$. In our algorithm, the number of peers conducted in active adjustment way is configurable; here we use the parameter k as the active adjustment number (0< k<n). In our scheme, among the k peers whose allocated resource is about to initiatively adjust and refine, the bandwidth of N_{r_1} ... $N_{r_{\lceil \frac{k}{2} \rceil}}$ (they consists of RSK, relative contribution small k-related set) is likely to decrease since they are the least relative contribution peers. While the bandwidth of $N_{r_{N-\lfloor \frac{k}{2} \rfloor+1}}$ ... N_{r_N} (they consists of RBK, relative contribution big k-related set) would possibly increase due to the fact that they possess highest relative contribution. In order to express more simply and clearly, we define the following sets based on peers' contribution in table 2. If a peer i in RSK set at the same time fall in ASK set, then the micro adjustment of such peer is assigned as ∇_{22} , otherwise if *i* belongs to ABK set, then the decline of bandwidth is assigned ∇_{21}. Supposing that the two scenarios are not suit for i, then its absolution contribution must lie in the intermediate range and i resides in AMK set, therefore, there is no adjustment needed at this round. In a similar way, peers in RBK are also assigned different adjustment quantum as $\triangle_{11}$ or $\triangle_{12}$, according the absolute contribution set they belong to.

3) Passive Adjustment Stage

After the active adjustment stage, the peers in RMK set come to the execution of passive adjustment stage. A difference would appear between the summation of allocated bandwidth to all competing nodes and the SN capacity due to the latest active adjustment. Then we distribute the difference bandwidth among the peers in RMK set proportionally to its relative contribution. If the summation of allocated bandwidth exceeds the SN capacity, e.g. $balance = W_s - \sum_i x_i$ is smaller than 0, we call it deficit state. Then the bandwidth resource of peers in RMK whose relative contribution is below average of all competing nodes is decreased with proportion to relative contribution, formally the offset change is $\frac{\mathrm{Re}l\mathrm{Con}_i}{\sum_k \mathrm{Re}l\mathrm{Con}_k} \times balance$. Otherwise, the allocated bandwidth falls short of the SN capacity, we call it surplus sate. Similarly, we increase the bandwidth resource of peers in RMK whose relative contribution is above the average of all competing nodes, in order to fully utilize the SN uploads bandwidth.

Table 2. The various contribution k-related set

Relative Contribution	RSK(relative contribution small k-related set)	The peers of k/2 with minimum relative contribution
	RBK(relative contribution big k-related set)	The peers of k/2 with maximum relative contribution
	RMK(relative contribution median k-related set)	The remaining peers other than nodes in RSK and RBK
Absolute Contribution	ASK(relative contribution small k-related set)	The peers of k/2 with minimum absolute contribution
	ABK(relative contribution big k-related set)	The peers of k/2 with maximum absolute contribution
	AMK(relative contribution median k-related set)	The remaining peers other than nodes in ASK and ABK

V. EVALUATION

In this section, we present several examples and simulations to illustrate the effectiveness and incentive properties of our resource allocation algorithm. At first, we start with the resource allocation fairness metric we have extended which is based on the Jain's Fairness Index.

A. *Contribution Weight Fairness Metrics (CFI)*

Jain's Fairness Index (FI) which originates from network flow evaluation is well accepted as a metric to evaluate the level of fairness of a resource allocation. Although the FI is well accepted, it does not take the weight of allocation into consideration. We extend the FI by replacing x_i by a contribution weighted one: $\tilde{x}_i = \frac{x_i}{w_i}$. Similarly, the weight of each allocation is given by a function of relative contribution and absolute contribution:

$W_i = f(RelCon_i,\ AbsCon_i)$. For example:

$$W_i = RelCon_i \times \log(AbsCon_i + 1). \qquad (3)$$

Therefore the extended Contribution Weight fairness Index (CFI) is expressed as.

$$\mathrm{CFI}\ (x_1, x_2, \ldots, x_n) = \frac{(\sum_{i=1}^{n} \tilde{x}_i)^2}{\sum_{i=1}^{n} w_i \times \sum_{i=1}^{n} \tilde{x}_i^2} \qquad (4)$$

We can utilize the CFI to judge whether a peer is receiving adequate and fair contribution matching resources. Similar to original FI, the larger value of CFI signify the much fairly of resource allocation, while the smaller of CFI, means that the allocation does not take relative contribution and absolute contribution in to consideration, thence induce much unfair in resource allocation.

B. *Numeric analysis of bandwidth allocation process*

Firstly, we consider a scenario where five competing nodes are requesting services from a SN that has the upload capacity of 5 Mb/s. Meanwhile, the five competing nodes (N1,N2,N3,N4,N5) are asking for bandwidth with the demand: [2,2,2,2,2] (in Mb/s). They possess different absolute contribution and WoC for the current observing window. Their absolute contribution vector: [40,30,20,5,5], relative contribution vector = [0.5,0.8,0.2,0.7,0.6]. In this example, we set the adjustment quantum sequence: $\alpha_n = \frac{1}{2\sqrt{n}}, \beta_n = \frac{1}{3n}$ respectively. The number of active adjustment parameter k sets 4, means four out of five computing peers would be rectified their bandwidth initiatively; the other one is adjusted passively. And the iterative stopping threshold of the Overall Adjustment Range is set 0.01.

Figure 2 shows the details of bandwidth allocation result and the corresponding CFI at each round. It is obviously at 12th round the micro-adjustment is converged. In more detailed analysis, we can see N2, N4 resides in RBK set, while N3,N5 stays in RSK set and N1 in RMK set. Therefore, during the second phase, their allocated resources are increased by different degree to reward their enthusiastic to participate in system. The increased range of N2 ($\triangle_{11}$) is larger than N4 ($\triangle_{12}$) for the total offset change quantum (the difference resource allocation between the initial round and the 12th round), and the differences are 0.388 and 0.198 respectively.

One the other hand, we can find N3 neither donates much capacity nor is unwilling to contribute, therefore, N3 experienced the decreasing quantum all the time. While N5 resides in the AMK, therefore no further of adjustment is conducted on N5. In 13th round the Overall Adjustment Range is below the threshold δ 0.01. Then the bandwidth allocation algorithm is finished with the eventually CFI 0.933407. And we see that Cowtra guarantees the resource adjustment converges quickly to the proper allocation: [1.8857, 1.6940, 0.5324, 0.6379, 0.2500] under this scenarior.

Figure 3 clearly shows that the Contribution Weight Fairness Index is increasing with the round goes. For example, when the active adjustment k is 1, we could find that CFI is started from the initial value of 0.749586 under the AC based resource allocation to 0.933407 after adjustment based on WC. It has been raised by 26%.

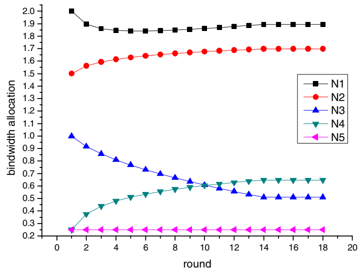

Figure 2. Resource Allocation with 5 competing nodes

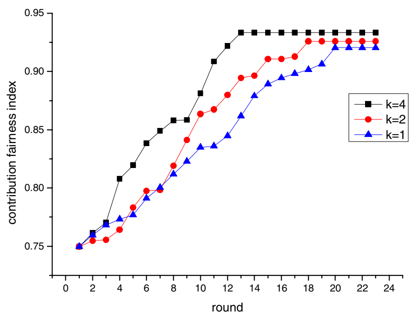

Figure 3. The effect of active adjustment parameter k

C. *The effect of active adjustment parameter k*

During the micro-adjustment phase, the choice of the active adjustment parameter k would affect the performance and fairness of our Cowtra algorithm. In this experiment we choose different k (k=4,3,1) to evaluate the effect produce on Cowtra. The other configuration settings are the same as in the former experiment. In figure 3, we could find that the algorithm is converged at 13th round under k=4 situation, while the other iterative rounds are 17 and 20 respectively when k is set by 2 and 1. In addition, the parameter k set by 4 also outperforms the other 2 configuration in term of the CFI. Therefore, we can draw the conclusion that a higher active adjustment parameter can produce better performance of our algorithm in term of converge speed as well as Contribution Fairness Index.

VI. CONCLUSION AND FUTURE WORK

Most resource allocation approaches neglect a important factor, namely relative contribution of a peer, we call it the willingness of contribution (WoC), which causes allocation unfair problem. In this paper we first present a novel resource allocation algorithm Cowtra to effectively distribute the SN upload bandwidth. We adjust the received bandwidth of each competing node according to their absolute and relative contribution. Simulation and numerical result shows the effectiveness and fairness of our algorithm. We will go to study how Cowtra works under churn in the future.

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