Fair Scheduling in Wireless Multi-Hop Self-backhaul Networks

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Abstract

In this paper, we provide guidelines for high throughput wireless multi-hop self-backhaul networks which at the same time retain fairness. Based on the theoretical analysis results, we propose two fair scheduling strategies: static independent fair scheduling and dynamic joint fair scheduling. Simulations verify that, both schemes can achieve maximum throughput and exhibits fairness between base stations in a multi-hop self-backhaul chain. Moreover, dynamic joint fair scheduling method achieves improved performance in throughput and exhibits better fairness in network environments where asymmetric services are presented.

1. Introduction

Though there have been many researches on wireless scheduling to produce a high performance broadband wireless access system [1][2][3], most of the studies dealt with uplink scheduling or assumed that uplink and downlink scheduling can be treated independently [4][5][6]. This kind of scheduling is generalized as independent scheduling strategy in the paper. In the early stage of wireless cellular networks roll out when subscriber numbers are low, for areas such as rural where wired link is not available, multi-hop self-backhaul becomes a very attractive solution for rapid deployment. The remainder of the paper is organized as follows: A framework describing wireless multi-hop self-backhaul system is presented in section II. In section III, we conduct theoretical analysis to provide guidelines for a high throughput wireless multi-hop self-backhaul network while exhibits fairness at the same time. In section IV, based on the theoretical analysis, we propose two fair scheduling strategies: static independent fair scheduling and dynamic joint fair scheduling. Afterwards, simulation results are provided to evaluate the proposed schemes. Finally, we give the conclusion in section V.

2. Wireless Multi-Hop Self-backhaul Networks

In typical wireless cellular network deployments, the base station (BS) is connected to external network via wired link. Figure 1-a is an wireless multi-hop self-backhaul network, which differs from a traditional wireless cellular network in that the backhaul subscriber station (BHS) which acts as a subscriber station (SS) of the BS provides wireless backhaul link for the BS, and there may be multi-hop for the BS to be connected to Internet.

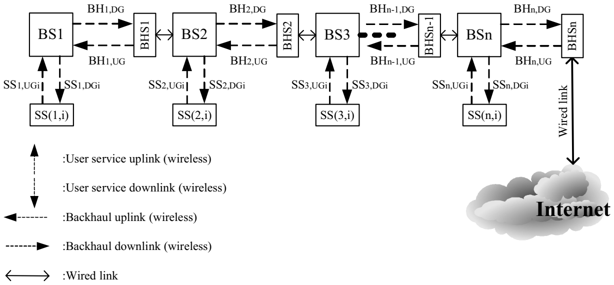

Figure. 1-a. Wireless multi-hop self-backhaul Networks

As shown in figure 1-a, BS_j allocates bandwidth for both local user access ($SS_{j,UGi}$, $SS_{j,DGi}$) and backhaul access ($BH_{j,UG}$, $BH_{j,DG}$), where $1 \le j \le n$.

Refer to figure 1-a and 1-b, in uplink direction, BS_1 gets local user traffic in upstream frame, then sends it to backhaul station BHS_1 in downstream frame; BHS_1 gets backhaul traffic from wireless backhaul link in downstream frame, then sends it to BS_2 via wired link; BS_2 gets local user traffic in upstream frame and gets traffic from BHS_1 via wired link, then sends them to

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BHS_2 in downstream frame via wireless backhaul link; Finally, backhaul traffic will arrive BHS_n which will forward the traffic to Internet via wired link. Similarly, in downlink direction, BHS_n gets traffic from Internet via wired link, then sends it to BS_n via wireless backhaul link; BS_n gets backhaul traffic from wireless backhaul link in upstream frame, then sends it to local SS in downstream frame if the traffic is for the local SS, else sends it to BHS_{n-1} via wired link; BHS_{n-1} gets traffic from wired link, then sends it to BS_{n-1} via wireless backhaul link; Finally, backhaul traffic will arrives BS_1 ; BS_1 gets the backhaul traffic from wireless backhaul link in upstream frame, then sends it to local SS in downstream frame.

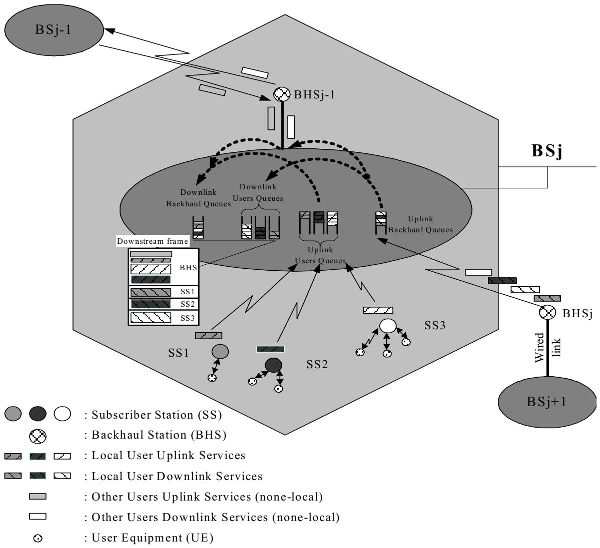

Figure. 1-b. BS and backhaul station

3. Theoretical Analysis

Refer to figure 1-a, wireless multi-hop self-backhaul networks can be mathematically described by:

$$\begin{cases} SS_{1,UG} + BH_{1,UG} \le BS_{1,U} \\ SS_{1,DG} + BH_{1,DG} \le BS_{1,D} \\ BH_{1,UG} \ge SS_{1,DG} \\ BH_{1,DG} \ge SS_{1,UG} \\ SS_{j,UG} + BH_{j,UG} \le BS_{j,U} \\ SS_{j,DG} + BH_{j,DG} \le BS_{j,D} \\ BH_{j,UG} \ge SS_{j,DG} + BH_{j-1,UG} \\ BH_{j,DG} \ge SS_{j,UG} + BH_{j-1,DG} \end{cases} , \quad 2 \le j \le n \qquad (1)$$

where n is the number of the base stations, $BS_{j,U}$ and $BS_{j,D}$ are the bandwidth capacities of the *j*-th BS, $SS_{j,UG}$ and $SS_{j,DG}$ are the bandwidth granted to local users of the *j*-th BS, $BH_{j,UG}$ and $BH_{j,DG}$ are the bandwidth granted to backhaul station BHS_j, where subscript U or D denotes uplink or downlink direction, respectively.

Using (1), we have:

$$\begin{cases} SS_{1,UG} + SS_{1,DG} \le \dfrac{BS_1}{2} \\ SS_{j,UG} + SS_{j,DG} + \dfrac{\sum_{i=1}^{j-1} (SS_{i,UG} + SS_{i,DG})}{2} \le \dfrac{BS_j}{2} \end{cases} , \quad 2 \le j \le n \qquad (2)$$

where BS_j denotes the overall bandwidth capacity of the *j*–th BS, with $BS_j = BS_{j,U} + BS_{j,D}$. To achieve fairness between BSs, the following equation must be met,

$$\begin{cases} BS_j \equiv \overline{BS} = \dfrac{1}{n} \times \sum_{1}^{n} BS_i = \dfrac{BS_{All}}{n} \\ k_j = \dfrac{SS_{j,UG} + SS_{j,DG}}{BS_j} \equiv k \end{cases} , \quad 1 \le j \le n \qquad (3)$$

where BS_{All} is the overall bandwidth capacity of the whole wireless multi-hop self-backhaul system, k_j is the overall bandwidth utilization efficiency of the *j*-th BS.

Using (2) and (3), we have,

$$\frac{k}{1 - 2 \times k} \le \frac{1}{j-1} \quad , \quad 2 \le j \le n \qquad (4)$$

so that we obtain:

$$k_{\max} = \frac{1}{n+1} \qquad (5)$$

where $k_{\max}$ is the maximum value of k. Obviously, the maximum bandwidth utilization efficiency is $\dfrac{BS_{All}}{n+1}$.

In summary, for a wireless n-hop self-backhaul system with capacity of BS_{All}, to achieve fairness between BSs while at the same time exhibits maximum bandwidth utilization efficiency, one should use the following criteria for scheduling:

$$\begin{cases} \left(SS_{j,UG}+SS_{j,DG}\right)\Big|_{\max} = \dfrac{\overline{BS}}{n+1} = \dfrac{BS_{All}}{n\times(n+1)} \\ \left(BH_{j,UG}+BH_{j,DG}\right)\Big|_{\max} = \dfrac{\overline{BS}\times j}{n+1} = \dfrac{BS_{All}\times j}{n\times(n+1)} \end{cases}, 1\le j\le n \qquad \mathbf{(6)}$$

4. Proposed Methods and Simulations

Using (6), we propose two fair scheduling strategies for wireless multi-hop self-backhaul networks.

4.1. Static Independent Fair Scheduling

This scheduling strategy allocates bandwidth for backhaul station statically. By setting $SS_{j,UG}\Big|_{\max} = SS_{j,DG}\Big|_{\max} \equiv \frac{\left(SS_{j,UG}+SS_{j,DG}\right)\Big|_{\max}}{2}$ and $BH_{j,UG} = BH_{j,DG} \equiv \frac{\left(BH_{j,UG}+BH_{j,DG}\right)\Big|_{\max}}{2}$, static independent fair scheduling strategy is described as:

$$\begin{aligned} & BS_j = \overline{BS} = \frac{BS_{All}}{n} \\ & BH_{j,UG} = BH_{j,DG} = \frac{\overline{BS}\times j}{2\times(n+1)} \\ & SS_{j,UG} = \min\left(SS_{j,U}, \frac{\overline{BS}}{2\times(n+1)}\right) \\ & SS_{j,DG} = \min\left(SS_{j,D}, \frac{\overline{BS}}{2\times(n+1)}\right) \\ & SS_{i,j,UG} = \frac{w_{i,j,U}\times SS_{i,j,U}}{\sum_{i=1}^{N_j}\left(w_{i,j,U}\times SS_{i,j,U}\right)}\times SS_{j,UG} \\ & SS_{i,j,DG} = \frac{w_{i,j,D}\times SS_{i,j,D}}{\sum_{i=1}^{N_j}\left(w_{i,j,D}\times SS_{i,j,D}\right)}\times SS_{j,DG} \end{aligned} \qquad \mathbf{(7)}$$

where $1\le j\le n$, $SS_{j,U}$ and $SS_{j,D}$ are the overall bandwidth requirements of the local users in the *j*-th cell. $SS_{i,j,U}$ and $SS_{i,j,D}$ are the bandwidth requests of SS *i* in the *j*-the cell, $w_{i,j,U}$ and $w_{i,j,D}$ are the weight factor of SS *i* in the *j*-th cell, $SS_{i,j,UG}$ and $SS_{i,j,DG}$ are the bandwidth granted to SS *i* in the *j*-the cell, where subscript U or D denotes uplink or downlink direction, respectively. Obviously, bandwidth granted for user uplink depends solely on the uplink requirement of the user, while bandwidth granted for user downlink depends solely on the downlink requirement of the user.

4.2. Dynamic Joint Fair Scheduling

According to the uplink and downlink bandwidth requirements of the users, this scheduling strategy dynamically allocates bandwidth for backhaul station. Dynamic joint fair scheduling strategy is described as:

$$\begin{aligned} & BS_j = \overline{BS} = \frac{BS_{All}}{n} \\ & BS_{j,U} = BS_{j,D} = \frac{\overline{BS}}{2} \\ & SS_{j,UG} = \frac{SS_{j,U}}{SS_{j,U}+SS_{j,D}}\times\min\left(\frac{BS_j}{n+1}, SS_{j,U}+SS_{j,D}\right) \\ & SS_{j,DG} = \frac{SS_{j,D}}{SS_{j,U}+SS_{j,D}}\times\min\left(\frac{BS_j}{n+1}, SS_{j,U}+SS_{j,D}\right) \\ & BH_{j,UG} = SS_{j,DG} + BH_{j-1,UG} \\ & BH_{j,DG} = SS_{j,UG} + BH_{j-1,DG} \\ & SS_{i,j,UG} = \frac{w_{i,j,U}\times SS_{i,j,U}}{\sum_{i=1}^{N_j}\left(w_{i,j,U}\times SS_{i,j,U}\right)}\times SS_{j,UG} \\ & SS_{i,j,DG} = \frac{w_{i,j,D}\times SS_{i,j,D}}{\sum_{i=1}^{N_j}\left(w_{i,j,D}\times SS_{i,j,D}\right)}\times SS_{j,DG} \end{aligned} \qquad \mathbf{(8)}$$

where $BH_{0,UG} = BH_{0,DG} = 0$, $SS_{j,U}$ and $SS_{j,D}$ are the overall bandwidth requirements of the local users in the *j*-th cell in uplink and downlink directions, respectively. Obviously, bandwidth granted for users uplink or downlink depends on bi-directional bandwidth requirements of the users.

By simulations, we compare the two fair scheduling strategies proposed above. In the simulation, we use a 2-hop 802.16 [7] self-backhaul network with overall bandwidth capacity of $BS_{All} = 100Mbps$. We specified five different traffic types for our simulations: Video conference, VoIP, FTP, HTTP, and Email. For each cell, there are: 1 video conference service, 20 VoIP services, 2 FTP services, 50 HTTP services and 30 Email services. To emulate service load in real networks, we use OPNET simulator to generate such services.

Figure 2 depicts the overall throughput comparing two schemes proposed. As expected, dynamic joint fair scheduling exhibits higher throughput. Figure 2 also verifies that, both methods achieve the maximum throughput of $33.3Mbps$, which is $\frac{BS_{All}}{n+1}$ as indicated in section III.

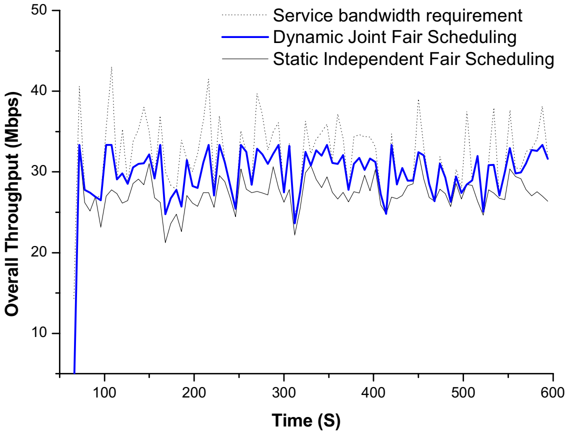

Figure. 2. Throughput for various scheduling strategies

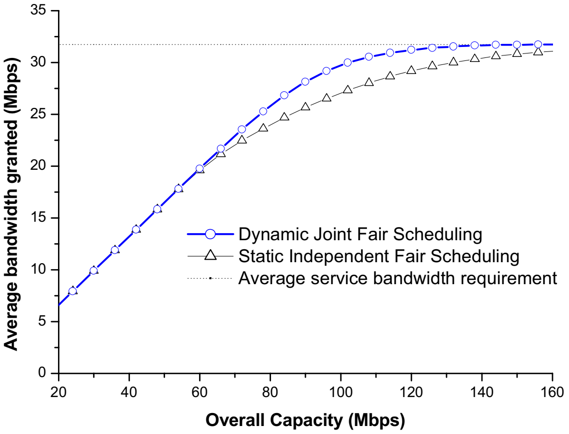

Figure. 3. Performance for the two fair scheduling methods

For various multi-hop network capacities, we got simulation results depicted in figure 3, which clearly indicates that the dynamic joint fair scheduling scheme has better performance than the static independent fair scheduling. We also notice that, when multi-hop self-backhaul network is highly overloaded or highly underloaded, the two fair scheduling methods actually exhibit similar performance in term of throughput.

By defining $R_j = \frac{SS_{j,UG} + SS_{j,DG}}{\sum_{i=1}^{n}\left(SS_{j,UG} + SS_{j,DG}\right)}$, which is the ratio between bandwidth granted by the j-th BS and the overall bandwidth granted by the multi-hop network, we can use R_j to measure the fairness of the j-th BS in a multi-hop self-backhaul chain. Obviously, a good fair scheduling method should have R_j close to $\frac{1}{n}$ as much as possible.

We conduct simulations for intensive asymmetric services configurations. The simulation results shown in figure 4 verified that, regardless of the factor r, which we denoted as the ratio between uplink bandwidth and downlink bandwidth of a asymmetric service, both fair scheduling schemes exhibit very good inter-BS fairness.

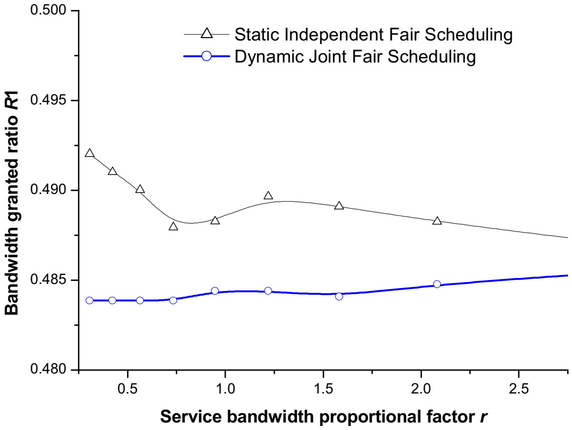

Figure. 4. Fairness under asymmetric services configurations

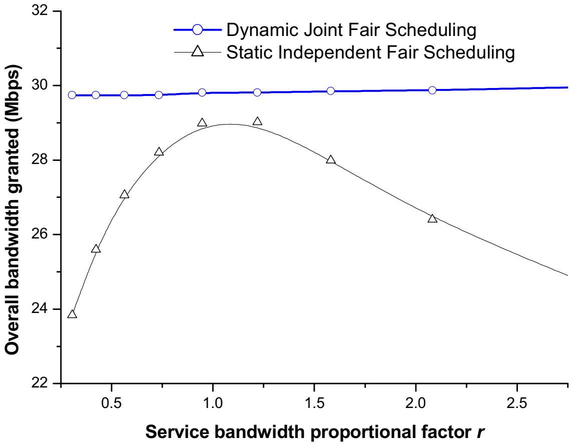

Figure. 5. Throughput under asymmetric services configurations

Figure 5 depicts the overall throughput under various asymmetric services configurations. As r reflects the asymmetry of the service, the simulation results clearly show that the static independent fair scheduling actually treats uplink and downlink service quite unfair, and that dynamic joint fair scheduling is more preferable especially in networks with asymmetric services.

These simulation results strongly indicate that, the proposed dynamic joint fair scheduling scheme can provide higher throughput while retains inter-BS fairness and fairness for asymmetric services at the same time for wireless multi-hop self-backhaul networks.

5. Concluding Remarks

In this paper, theoretical analysis is presented for fair scheduling in wireless multi-hop self-backhaul networks. Based on the theoretical analysis results, dynamic joint fair scheduling and static independent fair scheduling are then proposed. We conducted simulations to verify our proposed schemes. As expected, both scheduling strategies achieve maximum throughput while at the same time exhibit fairness between base stations in wireless multi-hop self-backhaul chain. Simulation results also demonstrated that, compared to the static independent fair scheduling scheme, the dynamic joint fair scheduling strategy can provide higher throughput, while retain uplink and downlink fairness for asymmetric services as well.

For fair scheduling, this paper does not consider the effect of time-variant or location-variant wireless backhaul channel status [8], which would be taken into account in our further studies on the fair scheduling of wireless multi-hop self-backhaul networks.

6. References

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