Bandwidth Allocation for 3-Sector Base Station in 802.16 Single-Hop Self-backhaul Networks

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Abstract—**Though IEEE 802.16 MAC protocols have been proposed to support quality of service (QoS) guarantees for various kinds of applications, they do not suggest how to allocate service bandwidth to fulfill QoS requirements. Most of the traditional methods of bandwidth allocation in wireless networks treat uplink and downlink bandwidth allocation independently. This research conducts theoretical analysis on the on-demand bandwidth allocation in an IEEE 802.16 single-hop self-backhaul network using 3-sector base station. Simulations have shown that such wireless backhaul systems using conventional on-demand bandwidth allocation will seriously suffer from fairness issues among different sectors of the base station. We then develop a new, joint dynamic bandwidth allocation algorithm for IEEE 802.16 single-hop self-backhaul network using 3-sector base station. Simulation results verified that, compared with conventional on-demand bandwidth allocation method, by considering both uplink and downlink bandwidth requests jointly, the proposed method is more bandwidth efficient and exhibits better fairness.**

Keywords-802.16; self-backhaul; on-demand bandwidth allocation

I. INTRODUCTION

Emerging as a broadband access technology capable of supporting both burst and isochronous applications, IEEE 802.16 technology has been accepted as the next-generation high-speed wireless communication system for future broadband services. With the rapid growth of wireless applications and the development of wireless technologies, IEEE 802.16 is also expected to provide services with quality of service (QoS) differentiated. Many advanced technologies, such as adaptive antenna array, space-time coding (STC), orthogonal frequency (OFDM), adaptive modulation and coding (AMC), even multiple-input multiple-output (MIMO) technique [2], [3], [4] have been applied in IEEE 802.16 networks for performance enhancement. As a key component for QoS provision in IEEE 802.16 media access control (MAC) framework, on-demand bandwidth allocation is specified in a general manner via bandwidth request/granted messages and polling mechanism, and the details of on-demand bandwidth allocation algorithm are left undefined such that product differentiations may be achieved through different vendor implementations. On the other side, in the early stage of IEEE 802.16 networks roll out when subscriber numbers are low, for areas such as rural where wired link is not available, single-hop self-backhaul is deemed to be a very attractive solution for rapid deployment. Being an effective approach to improve capacity of wireless networks, cell sectorization is usually implemented in real IEEE 802.16 network deployments. More specifically, 3-sector base station (BS) is most often seen in an IEEE 802.16 multi-sector cell. Therefore, the purpose of the research is to study the on-demand bandwidth allocation for the 3-sector BS in IEEE 802.16 single-hop self-backhaul network. The remainder of the paper is organized as follows: A reference framework describing IEEE 802.16 single-hop self-backhaul system using 3-sector BS is presented in section II. In section III, a conventional method of on-demand bandwidth allocation for the 3-sector BS in an IEEE 802.16 single-hop self-backhaul network is introduced first, and based on the theoretical analysis results, we then propose the joint dynamic bandwidth allocation (JDBA) algorithm to be used in such wireless backhaul systems. Afterwards, various simulations are performed in section IV to compare the proposed method with the conventional one. Finally, we give the conclusion in section V. Appendix details the theoretical derivation for section III.

II. BACKGROUND

Figure 1 depicts an IEEE 802.16 single-hop self-backhaul network using 3-sector BS. One would have noticed that there is a distinct difference between the traditional IEEE 802.16 network and the self-backhaul network shown in figure 1.

In a typical IEEE 802.16 network, there exists wired link between the BS and the external wired network,

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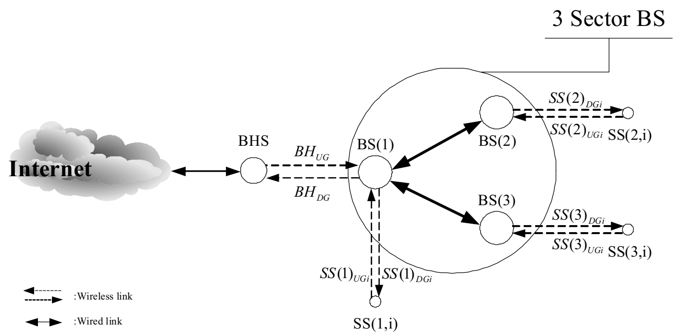

Figure 1. IEEE 802.16 Single-Hop Self-backhaul Network using 3-Sector BS

1. In downlink direction, the BS receives traffic (downlink traffic to SSs) from the external network via wired link and distributes it to corresponding sectors ($BS(1)$, $BS(2)$ and $BS(3)$) which will then deliver the downlink traffic to the destination subscriber stations (SSs).

2. In uplink direction, the BS receives uplink traffic from the source SSs of the three sectors, and then sends it to the external wired network via wired link.

On the other hand, for an IEEE 802.16 single-hop self-backhaul network shown in figure 1, there is no direct wired link between the BS and the external wired network,

1. In downlink direction, the backhaul SS (BHS) receives traffic(downlink traffic to SSs) from external network via wired link, then puts it into upstream frames and sends to one sector (say $BS(1)$ in figure 1) of the BS via wireless link. $BS(1)$ receives downlink traffic from the BHS via wireless link and distributes it to corresponding sectors which will then deliver the downlink traffic to the destination SSs.

2. In uplink direction, $BS(1)$ receives uplink traffic from the source SSs, puts it into downstream frames and sends to the BHS via wireless link. The BHS gets traffic via wireless link and sends it to the external network via wired link.

Obviously, an IEEE 802.16 single-hop self-backhaul network differs from a traditional one in that the BHS which acts as a SS of the BS also provides wireless backhaul link for the BS.

III. THEORETIACAL ANALYSIS

Refer to figure 1, we denote $SS(j)_{UG} = \sum_{i=1}^{Nj} SS(j)_{UGi}$ and $SS(j)_{DG} = \sum_{i=1}^{Nj} SS(j)_{DGi}$, where $j = 1 \sim 3$, N_j is the number of SSs in the j-th sector, $SS(j)_{UGi}$ and $SS(j)_{DGi}$ are the uplink and downlink bandwidth granted to SS i in the j-the sector, respectively, we then have following relationship,

$$\begin{cases} SS(1)_{UG} + BH_{UG} \le BS(1)_U \\ SS(1)_{DG} + BH_{DG} \le BS(1)_D \\ BH_{UG} \ge SS(1)_{DG} + SS(2)_{DG} + SS(3)_{DG} \\ BH_{DG} \ge SS(1)_{UG} + SS(2)_{UG} + SS(3)_{UG} \\ SS(2)_{UG} \le BS(2)_U \\ SS(2)_{DG} \le BS(2)_D \\ SS(3)_{UG} \le BS(3)_U \\ SS(3)_{DG} \le BS(3)_D \end{cases} \tag{1}$$

where $BS(j)_U$, $BS(j)_D$ are the overall capacities of the j-th sector ($j = 1 \sim 3$), $SS(j)_{UG}$ and $SS(j)_{DG}$ are the service bandwidth granted by the j-th sector, BH_{UG} , BH_{DG} are the backhaul bandwidth granted to the BHS, where subscript or denotes uplink or downlink direction, respectively.

A. *Conventional Method (ISBA)*

For the network depicted in figure 1, independent static bandwidth allocation (ISBA) policy is often implemented. The BS applying the ISBA scheme allocates fix bandwidth to the BHS and the bandwidth granted to the SS in one direction depends solely on the bandwidth request of the SS in that direction. The ISBA method can be mathematically written as:

$$\begin{cases} BH_{UG} = C_U \\ BH_{DG} = C_D \\ SS(1)_{UG} = \min(BH_{DG} \times \dfrac{SS(1)_U}{\sum_{j=1}^{3} SS(j)_U}, SS(1)_U, BS_U - BH_{UG}) \\ SS(1)_{DG} = \min(BH_{UG} \times \dfrac{SS(1)_D}{\sum_{j=1}^{3} SS(j)_D}, SS(1)_D, BS_D - BH_{DG}) \\ SS(2)_{UG} = \min(BH_{DG} \times \dfrac{SS(2)_U}{\sum_{j=1}^{3} SS(j)_U}, SS(2)_U) \\ SS(2)_{DG} = \min(BH_{UG} \times \dfrac{SS(1)_D}{\sum_{j=1}^{3} SS(j)_D}, SS(j)_D) \\ SS(3)_{UG} = \min(BH_{DG} \times \dfrac{SS(3)_U}{\sum_{j=1}^{3} SS(j)_U}, SS(3)_U) \\ SS(3)_{DG} = \min(BH_{UG} \times \dfrac{SS(3)_D}{\sum_{j=1}^{3} SS(j)_D}, SS(3)_D) \\ SS(j)_{UGi} = \dfrac{w_{i,j,U} \times SS(j)_{Ui}}{\sum_{i=1}^{N_j} \left(w_{i,j,U} \times SS(j)_{Ui} \right)} \times SS(j)_{UG} \\ SS(j)_{DGi} = \dfrac{w_{i,j,D} \times SS(j)_{Di}}{\sum_{i=1}^{N_j} \left(w_{i,j,D} \times SS(j)_{Di} \right)} \times SS(j)_{DG} \end{cases} \tag{2}$$

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where C_U , C_D are the constant bandwidth granted to BHS, $SS(j)_U$ and $SS(j)_D$ are the overall bandwidth requests of all SSs in the j-th sector, $SS(j)_{Ui}$ and $SS(j)_{Di}$ are the bandwidth requests of SS i in the j-the sector, $w_{i,j,U}$ and $w_{i,j,D}$ are the weight factor of SS i in the j-th sector, $SS(j)_{UGi}$ and $SS(j)_{DGi}$ are the bandwidth granted to SS i in the j-the sector, where subscript U or D denotes uplink or downlink direction, respectively. One can verify that the scheme described by (2) satisfies relationship (1).

By various simulations, we have found that, for $BS_U = BS_D = B$, to use bandwidth efficiently, C_U and C_D should be in the range of $(0.6{\sim}0.8)\times B$.

As the ISBA treats sector 1 (the sector providing the self-backhaul link) and the other sectors differently, there are fairness issues which will be illustrated in section IV.

B. Joint Dynamic Bandwidth Allocation (JDBA) Scheme

Apparently, one can use the following strategy to improved inter-sector fairness:

$$\begin{cases} SS(j)_{UG} = \min\left(W_U \times SS(j)_U, SS(j)_U\right) \\ SS(j)_{DG} = \min\left(W_D \times SS(j)_D, SS(j)_D\right) \end{cases} (j = 1 \sim 3) \qquad (3)$$

where both W_U and W_D ($W_U \ge 0, W_D \ge 0$) are adaptively adjusted according to the bandwidth request of the system and are equal for all sectors. Bandwidth allocation conform to (3) improves fairness among different sectors of a multi-sector BS.

We then propose the *joint dynamic bandwidth allocation* (JDBA) method, which maximize the overall bandwidth utilization (see Appendix for reference):

$$\begin{cases} SS(j)_{UG} = \min\left(\dfrac{BS_D \times SS_D - BS_U \times SS(1)_D}{(SS_U \times SS_D - SS(1)_U \times SS(1)_D)} \times SS(j)_U, SS(j)_U\right) \\ SS(j)_{DG} = \min\left(\dfrac{BS_U \times SS_U - BS_D \times SS(1)_U}{(SS_U \times SS_D - SS(1)_U \times SS(1)_D)} \times SS(j)_D, SS(j)_D\right) \\ BH_{UG} = BS_U - SS(1)_{UG} \\ BH_{DG} = BS_D - SS(1)_{DG} \\ SS(j)_{UGi} = w_{i,j,U} \times SS(j)_{Ui} \times SS(j)_{UG} \Big/ \sum_{i=1}^{N_j} \left(w_{i,j,U} \times SS(j)_{Ui}\right) \\ SS(j)_{DGi} = w_{i,j,D} \times SS(j)_{Di} \times SS(j)_{DG} \Big/ \sum_{i=1}^{N_j} \left(w_{i,j,D} \times SS(j)_{Di}\right) \end{cases} \qquad (4)$$

It is clear that, in a JDBA-capable 802.16 single-hop self-backhaul network, the BS allocates bandwidth to the BHS dynamically, and the uplink or downlink bandwidth granted to the SS is dependent on both uplink and downlink bandwidth requests of the system. Obviously, the JDBA algorithm differs from current bandwidth allocation algorithms in that most of the existing methods assume that uplink and downlink bandwidth allocation can be treated independently [5], [6], [7]. We will show in next section that by considering both uplink and downlink bandwidth requests jointly, the JDBA method achieves higher bandwidth utilization and better fairness.

IV. NUMERICAL SIMULATIONS

In the simulation, we use an IEEE 802.16 single-hop self-backhaul network using 3-sector BS with sector capacity of $BS_U = BS_D = B = 35Mbps$. For each sector, there are: 1 video conference service, 20 VoIP services, 2 FTP services, 50 HTTP services and 30 Email services. OPNET network simulator [8] is used to generate such service pattern.

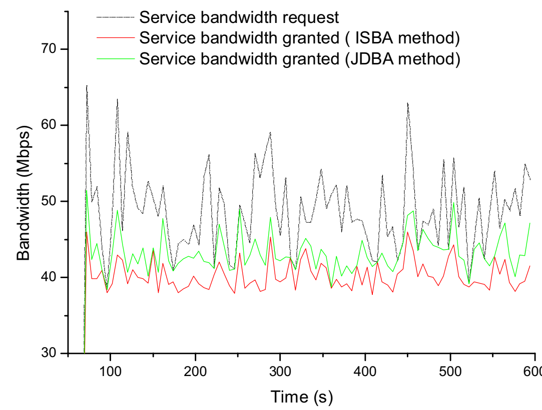

Figure 2. Overall service bandwidth granted

Figure 2 illustrates the overall bandwidth granted by the whole system when applying different methods. It clearly indicates that the JDBA method can achieve higher bandwidth utilization than the conventional scheme.

We then evaluate the performance of the two methods under two service scenarios.

For service scenario I, the overall service load is average distributed among the sectors statistically. As expected, the simulation result depicted in figure 3 verifies that, while the conventional method treats sector 1 unfairly, the JDBA scheme does not have inter-sector fairness issue in this service scenario. One can verify that, for the two fair scheduling proposed, the maximum throughput is about $33.3Mbps$, which is $BS_{All}/(n+1)$, for $n = 2$.

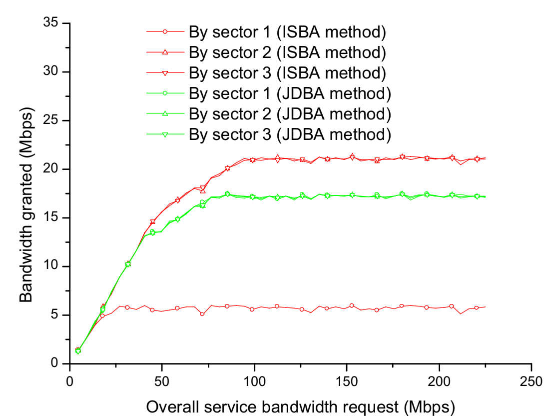

Figure 3. Service bandwidth granted by different sectors

Figure 4 is the overall bandwidth granted for various service loads. It can be seen that, more service bandwidth request (about $40Mbps$) will be fulfilled for the JDBA method (comparing to about $15Mbps$ for the conventional method).

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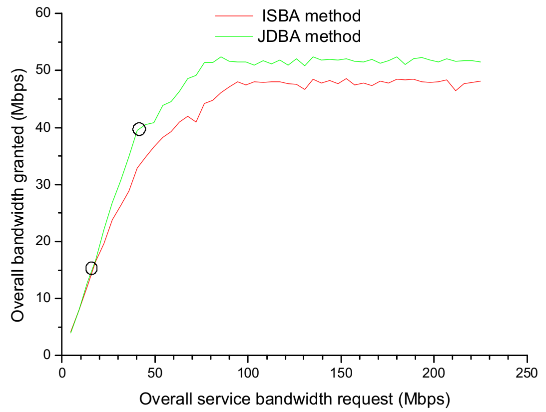

Figure 4. Overall service bandwidth granted in service scenario I

For the JDBA method in the scenario ($B = 35Mbps$), figure 4 also indicates a maximum bandwidth utilization of $52.5Mbps$ which can be verified that $Util|_{\max} = 1.5 \times B$ (see Appendix for reference).

For service scenario II, we conduct simulations for the following service patterns:

1. Change sector 1's service load, while keep the other two's service load fixed;

2. Change sector 2 (or 3) 's service load, while keep the other two's fixed;

Let say, we are now changing sector j's service load, we define proportion factor $K = \dfrac{SS(j)_{UG} + SS(j)_{DG}}{\sum_{i=1}^{3} \left(SS(j)_{UG} + SS(j)_{DG} \right)}$.

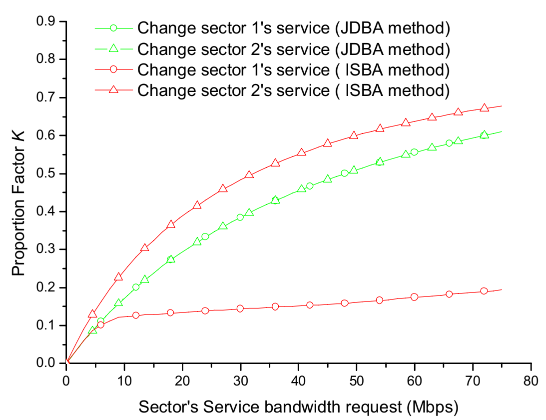

Figure 5. Inter-sector fairness in service scenario II

Obviously, a good bandwidth allocation method should produce same K for the above two service patterns. The simulation results in figure 5 clearly indicates that, contrary to systems implementing the conventional bandwidth allocation method, in a JDBA-capable system, user will be granted same bandwidth no matter which sector it is in.

All these simulation results strongly verify that the JDBA method is superior to the conventional ones which normally do not consider both the uplink and downlink bandwidth request at the same time in bandwidth allocating.

V. Conclusion Remark

Being an integrated part in 802.16 standard, on-demand bandwidth allocation is deemed to be a key component in QoS provision. This research focuses on bandwidth allocation in 802.16 networks. More specifically, it targets for efficient and fair on-demand bandwidth allocation for the 3-sector BS in 802.16 single-hop self-backhaul networks.

Based on the theoretical analysis, the JDBA method is proposed and evaluated. Comparisons with a conventional have verified that, due to the fact that the JDBA method allocates bandwidth based on both the uplink and downlink requests of the system, the proposed algorithm achieves higher bandwidth utilization. Moreover, the JDBA scheme exhibits better fairness among sectors of a 3-sector BS. Consequently, we conclude that, to use bandwidth more efficiently and fairly, the on-demand bandwidth allocation in 802.16 single-hop self-backhaul networks should consider both the uplink and downlink bandwidth requests at the same time.

Though this research deals with 3-sector BS only, it can be easily extended to BS with more than three sectors in 802.16 single-hop self-backhaul networks.

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Appendix: Theoretical Derivation

Using (1) and (3), we have following relationship,

$$\begin{cases} W_U \times \sum_{j=1}^{3} SS(j)_U \le BS_D - W_D \times SS(1)_D \\ W_D \times \sum_{j=1}^{3} SS(j)_D \le BS_U - W_U \times SS(1)_U \end{cases} \tag{5}$$

where $W_U \ge 0, W_D \ge 0$.

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Defining $\begin{cases} A_U = W_U \times \sum_{j=1}^{3} SS(j)_U = W_U \times SS_U \\ A_D = W_D \times \sum_{j=1}^{3} SS(j)_D = W_D \times SS_D \end{cases}$, we then have,

$$\begin{cases} A_U + A_D \times SS(1)_D / SS_D \le BS_D \\ A_D + A_U \times SS(1)_U / SS_U \le BS_U \end{cases} \qquad (6)$$

where $A_U \ge 0, A_D \ge 0$.

From (3), we know that for overloaded network environments, the overall bandwidth utilization can be expressed as $Util = A_U + A_D$. To maximize overall bandwidth utilization for overloaded network environments, from (6), we depict the intersect area for possible value of A_U and A_D in 2-D plot (refer to figures 6, 7, 8),

1. When $\begin{cases} SS(1)_U = SS_U \\ SS(1)_D = SS_D \end{cases}$, bandwidth utilization is maximized with $Util|_{\max} = \min(BS_U, BS_D)$ when $\begin{cases} A_U = C \\ A_D = \min(BS_U, BS_D) - C \end{cases}$, where C can be any value satisfying $0 \le C \le \min(BS_U, BS_D)$. Indeed, one would set $C = \min(BS_U, BS_D) \times SS_U / (SS_U + SS_D)$ to further maintain the fairness of bandwidth utilization between uplink and downlink.

When $\begin{cases} BS_U \times SS(1)_D / SS_D \le BS_D \\ BS_D \times SS(1)_U / SS_U \le BS_U \end{cases}$, refer to figure 2, by moving line $Util = A_U + A_D$ to intersect with the intersect area, we have

$$Util|_{\max} = \frac{BS_U \times (SS_U - SS(1)_U) \times SS_D + BS_D \times (SS_D - SS(1)_D) \times SS_U}{(SS_U \times SS_D - SS(1)_U \times SS(1)_D)}$$

when $\begin{cases} A_U = \dfrac{SS_U \times (BS_D \times SS_D - BS_U \times SS(1)_D)}{(SS_U \times SS_D - SS(1)_U \times SS(1)_D)} \\ A_D = \dfrac{SS_D \times (BS_U \times SS_U - BS_D \times SS(1)_U)}{(SS_U \times SS_D - SS(1)_U \times SS(1)_D)} \end{cases}$. Obviously, if $BS_U = BS_D$, then we have $\begin{cases} BS_U \times SS(1)_D / SS_D \le BS_D \\ BS_D \times SS(1)_U / SS_U \le BS_U \end{cases}$ for all possible service requests.

2. When $BS_U \times SS(1)_D / SS_D > BS_D$, refer to figure 3, by moving line $Util = A_U + A_D$ to intersect with the intersect area, we have $Util|_{\max} = BS_D \times SS_D / SS(1)_D$ when $\begin{cases} A_U = 0 \\ A_D = BS_D \times SS_D / SS(1)_D \end{cases}$.

3. When $\dfrac{BS_D \times SS(1)_U}{SS_U} > BS_U$, refer to figure 4, by moving line $Util = A_U + A_D$ to intersect with the intersect area, we have $Util|_{\max} = \dfrac{BS_U \times SS_U}{SS(1)_U}$ when $\begin{cases} A_U = \dfrac{BS_U \times SS_U}{SS(1)_U} \\ A_D = 0 \end{cases}$.

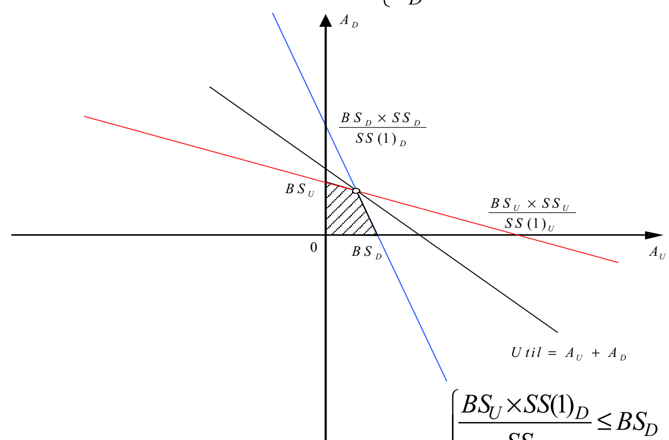

Figure. 6. Maximum bandwidth utilization when $\begin{cases} \dfrac{BS_U \times SS(1)_D}{SS_D} \le BS_D \\ \dfrac{BS_D \times SS(1)_U}{SS_U} \le BS_U \end{cases}$

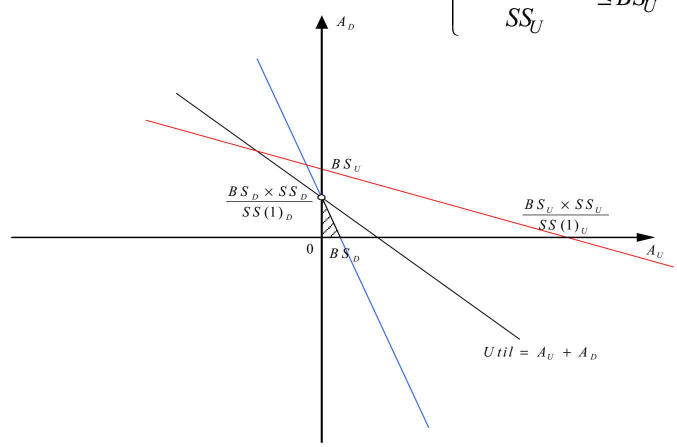

Figure. 7. Maximum bandwidth utilization when $\dfrac{BS_U \times SS(1)_D}{SS_D} > BS_D$

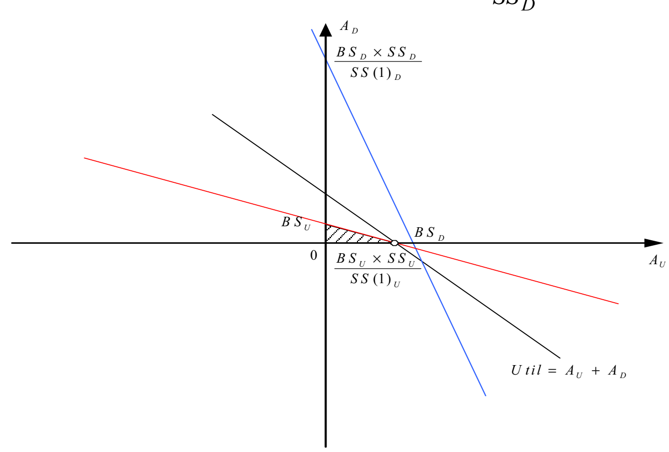

Figure. 8. Maximum bandwidth utilization when $\dfrac{BS_D \times SS(1)_U}{SS_U} > BS_U$

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