Chapter 4
Wireless Backhaul Optimization Algorithm in 5G Communication

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Abstract A wireless backhaul optimization approach using a delay jitter is suggested to handle the wireless backhaul issue for 5G dynamic heterogeneous situations. First, the delay and delay jitter issues in 5G dynamic heterogeneous situations are carefully evaluated, optimization indicators are defined, and the fundamental backhaul model is further built. Then, considering the optimization action needs, include delay constraints to create better model 1; examine network overload, relax channel number allocation variables to construct improved model 2, and present a matching hierarchical method for a quick solution. The simulation results reveal that the suggested approach has improved delay jitter performance compared with three kinds of current wireless backhaul optimization algorithms.

Keywords 5G communication · Wireless network · Heterogeneous scenarios · Hierarchical algorithm · Backhaul algorithm

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The original version of this chapter was revised: The name of the author Astha Sharma and the affiliation have been updated. The correction to this chapter is available at https://doi.org/10.1007/978-981-99-3668-7_14

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B. Bhushan et al. (eds.), *5G and Beyond*, Springer Tracts in Electrical and Electronics Engineering, https://doi.org/10.1007/978-981-99-3668-7_4

Introduction

With the rapid development of science and technology and the continuous improvement of people's living standards, various types of mobile terminal equipment and mobile Internet services are widely used. It is estimated that by 2030, the number of mobile terminals will be close to 100 billion, and mobile service traffic will increase by nearly 20,000 times (Ge et al. 2019; Wang et al. May 2016). It will be difficult for the existing communication system to meet the access requirements of massive terminals and services in the future. In view of this, the fifth generation mobile communication system (5G) (Zhang et al. 2020; Madapatha et al. 2021) emerges as the times require. On the other hand, with the gradual rise of various interactive multimedia services (such as video conferencing and online games, etc.), delay and delay jitter have increasingly become the most important QoS indicators, and become the key to user service experience (Chaudhry et al. 2020a; Ahmad 2015). The current research mainly focuses on the analysis of the delay characteristics of data packets, and there are relatively few studies on delay jitter. Therefore, it is imperative to study the delay jitter for the 5G environment.

The control of service delay and delay jitter is mainly implemented at the network link layer with the packet as the granularity, and the forwarding scheduling and queue management of the data packets are carried out through the network nodes. At present, the results of studying delay jitter performance with packet as granularity are rare. References (Rezaabad et al. 2018; Hore et al. 2021) have explored the network delay jitter characteristics. Reference (Chaudhry et al. 2020b) uses delay mean square error to approximate the delay jitter for multi-hop wireless Mesh networks and obtains the delay jitter by solving the end-to-end delay distribution. It should be noted that most of the literature on delay jitter research is based on single-point systems, such as only studying the delay jitter of wireless access network or wired core network (Tran and Le 2018; Pham et al. 2019). However, the 5G network must be a complex and diverse heterogeneous network, and the backhaul network is an important part. The unified consideration of the access network and the backhaul network can more truly describe the future 5G network.

Therefore, in the assessment of the existing problems, this paper suggests an optimal channel resource allocation algorithm with delay jitter as the optimization index for the 5G hybrid backhaul scenario. Considering the dynamic characteristics of the channel, the delay jitter problem is comprehensively analyzed, the delay jitter index is obtained, and then various backhaul optimization models are constructed. Finally, the hierarchical algorithm is used to solve the problem quickly.

The rest of the chapter is organized as follows: section "Network Scenarios and System Assumptions" covers the 5G network scenario, section "Analysis of Delay Jitter Indicators" includes the analysis of delay jitter indicators, section "Optimization Model Establishments" includes the proposed model description, section "Improved Model Solutions" includes the improved model, section "Simulation Analysis" includes the simulation detail and result analysis, and at last, section "Conclusions" includes the conclusion and future work.

Network Scenarios and System Assumptions

As shown in Fig. 4.1, for a two-layer heterogeneous network scenario, the upper layer is a Backhaul Aggregator Node (BAN). The lower layer is multiple Small-Cell Base stations (SCBS) covered by the BAN. Dedicated optical fibers link the BAN to the rest of the network, and millimeter waves are used for communication with SCBS or end customers (Iradukunda et al. 2021).

While SCBS uses frequency bands below 6 GHz (Liu et al. 2020) to communicate with users, here, the BAN combines the functions of an aggregator and base station access. Considering the hybrid backhaul scenario, there are two backhaul methods to choose from: the first one, the user can attach to the BAN via a one-hop wireless connection, and the BAN will handle the backup via an Ethernet cable; the second one, the user can access the SCBS to which he belongs, and then owned by.

The SCBS accesses the BAN and the core network through a two-hop wireless link.

Define SCBS set SC = $\{C_1, C_2, \ldots, C_1, \ldots, C_L\}$, define the user set covered by cell C_1 as $UE_1 = \{UE_{11}, UE_{12}, \ldots, UE_{ln}, \ldots, UE_{lNl}\}$, where UE_{ln} represents the nth user, N_1 is the number of users in the cell SC_1. It is assumed that all SCBSs have a common channel. Now, the seamless coverage of the entire network is disjoint, that is, $UE_i \bigcap UE_j = \emptyset \ (i \neq j)$. Therefore, the set of users is $UE = \{UE_1, UE_2, \ldots, UE_1, \ldots, UE_L\}$, then the number of users $N = \sum_{l=1}^{L} N_l$.

The access selection vector is defined as

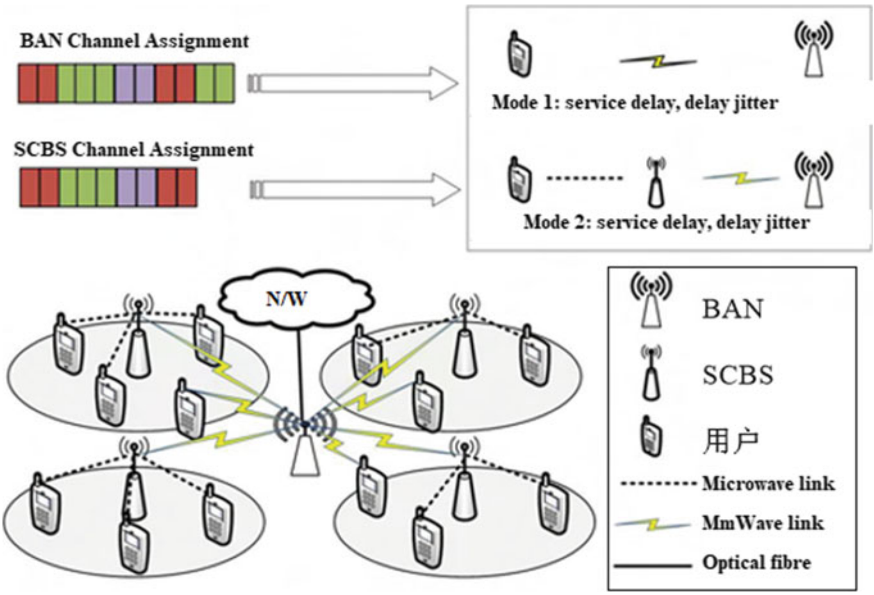

Fig. 4.1 5G two-layer heterogeneous network scenario

$$A = \{a_{11}, a_{12}, \ldots, a_{1N_2}, a_{21}, a_{22}, \ldots, a_{2N_2}, \ldots, a_{L1}, a_{L2}, \ldots, a_{LN_L}\}$$

Among them, $a_{ln} = 1$ $(n \leq N_1)$ means that user n in cell C_1 accesses the BAN, and the BAN performs the backhaul; $a_{ln} = 0$ $(n \leq N_1)$ means that the user n in cell C_1 accesses the C_1, and the C_1 performs the backhaul.

The channel allocation matrix that defines SCBS is

$$B = \begin{bmatrix} b_{11,1} & b_{11,2} & \ldots & b_{11,M_1} \\ b_{12,1} & b_{12,2} & \ldots & b_{12,M_1} \\ \vdots & \vdots & b_{ln,m} & \vdots \\ b_{1N_1,1} & b_{1N_1,2} & \ldots & b_{1N_1,M_1} \\ b_{21,1} & b_{21,2} & \ldots & b_{21,M_1} \\ b_{22,1} & b_{22,2} & \ldots & b_{22,M_1} \\ \vdots & \vdots & \ldots & \vdots \\ b_{1N_2,1} & b_{2N_2,2} & \ldots & b_{2N_2,M_1} \\ \vdots & \vdots & \ldots & \vdots \\ b_{LN_L,1} & b_{LN_L,2} & \ldots & b_{LN_L,M_1} \end{bmatrix}$$

Among them, $b_{ln,m} = 1$ shows that the bandwidth W_m is allocated to the user $\mathrm{UE_{ln}}$, and $b_{ln,m} = 0$ suggests that it is not given. Here, $W = \{W_1, W_2, \ldots, W_{M_1}\}$ denotes the channel vector that SCBS can allocate, and M_1 is the total number of SCBS channels.

The BAN channel distribution vector is defined as below, where M_2 is the total number of channels in BAN

$$C = \{c_{11}, c_{12}, \ldots, c_{1N_1}, \ldots, a_{11}, a_{12}, \ldots, c_{\mathrm{ln}}, \ldots, c_{lN_l}, \ldots, c_{L1}, c_{L2}, \ldots, c_{LN_L}\}$$

The number of BAN channels assigned to UEln is denoted by c_{ln} and c_{ln} $1(l,n)$. It's important to remember that users require a certain quantity of BAN capacity whether they use the BAN backhaul or the SCBS backhaul. cln displays the number of channels assigned to the Cl BAN link in the UEln Cl BAN route for UEln packet transmission if aln is set to 1; otherwise, cln displays the number of channels assigned to the UEln BAN link for UEln data packet transmission if aln is set to 0.

The paper's method has been based on the following principles:

(1) Assuming that the channels are discrete, the BAN can assign different tracks to any SCBS or a particular user. The SCBS can also set other numbers of media to a specific user.
(2) For the service uplink transmission scenario, study the delay jitter index based on packet granularity.

(3) To simplify interference analysis, we will presume that the BAN and SCBS channels have the same total bandwidth, and the BAN's total bandwidth should be larger than the SCBS's total bandwidth.
(4) If the link's transmission rate is higher than its channel capacity, wireless packet loss will occur; each SCBS has an unlimited wait buffer to prevent packet loss from accumulating (or overcrowding); and if the link experiences packet loss, the transmission mechanism will resume to transmit the packet again.

Analysis of Delay Jitter Indicators

In the wireless communication environment, delay jitter is a physical quantity that measures the delay change experienced by data packets during network transmission—packet delay jitter. Therefore, to analyze the delay jitter problem, it is necessary to examine the delay problem first. Propagation delay and transmission delay are components of link delay. Propagation delays are affected by a number of factors, including the distance over which a signal must travel and the pace at which electromagnetic waves travel. (i.e., the speed of light). Due to the short distances over which 5G signals must travel, transmission delays are negligible. However, data fragment transfer causes a delay, which is known as transmission delay. Therefore, the analysis of the service delay and delay jitter system is analyzed separately below.

Delay Analysis

In this scenario, there are three types of wireless links for UE_{ln}: the link l_{ln}^1 for UE_{ln} to access BAN, the link for UE_{ln} to access SC_l l_{ln}^2, and the link for SC_l to access BAN correspondingly l_{ln}^3. All link channels are assumed to be subject to small-scale Rayleigh fading. For links l_{ln}^1 and l_{ln}^3, since the same track is not repeatedly allocated in the BAN, there is no interference in the BAN;

Both use millimeter wave communication, and the distance between BANs is relatively long. The above analysis denotes the signal-to-interference noise ratio of the link l_{ln}^i as $SINR_{ln}^i$. If $SINR_{ln}^i \geq SINR_{th}$, the transmission is considered successful, and the bit error rate BER_{ln}^i of the link l_{ln}^i is calculated.

Channel error correction coding is linked to the data loss rate. It is believed that the capacity of all packages is PL (PL $\geq$ 3). According to this report, the data package has three mistakes, or bits, and the box is presumed gone. If there is a loss of packets and the data has to be reissued, the packet loss rate is

$$PER_{ln}^i = 1 - (1 - BER_{ln}^i)^{PL} - C_{PL}^1 (1 - BER_{ln}^i)^{PL-1} BER_{ln}^i - C_{PL}^2 (1 - BER_{ln}^i)^{PL-2} (BER_{ln}^i)^2 \tag{4.1}$$

C_θ^ϑ represents the number of combinations to select ϑ elements from θ elements. Link l_{ln}^i is derived from the packet loss rate average transmission delay for

$$\tau_{ln}^i = (1 - PER_{ln}^i)T + PER_{ln}^i(1 - PER_{ln}^i)2T + \cdots + \left(PER_{ln}^i\right)^{RT} \\ (1 - PER_{ln}^i)(RT + 1)T + \left(PER_{ln}^i\right)^{RT+1}(RT + 1)T \tag{4.2}$$

T represents a transmission delay, while RT is the greatest number of retransmissions.

The latency study of the UE $\rightarrow$ BAN route is straightforward once we move beyond the connection level. With a one-hop wireless link, the latency introduced by the cable central network is negligible and not worth considering. Therefore, for the UE $\rightarrow$ SC $\rightarrow$ BAN path, the time for Packet1, Packet2, Packet3, …, Packet k to reach SC_1 isτ_{ln}^2, $2\tau_{ln}^2$, $3\tau_{ln}^2$, ···, $k\ \tau_{ln}^2$ in sequence. If $\tau_{ln}^2 \geq \tau_{ln}^3$, there is no queue congestion at SC_1, so the time to reach BAN is $\tau_{ln}^2+\tau_{ln}^3$, $2\ \tau_{ln}^2+\tau_{ln}^3$, $3\ \tau_{ln}^2+\tau_{ln}^3, \cdots, k\ \tau_{ln}^2+\tau_{ln}^3$. If $\tau_{ln}^2<\tau_{ln}^3$, there is a queuing delay in SC_1, so the queuing delay in $SC_1$is 0 in sequence, $\tau_{ln}^3 - \tau_{ln}^2$,$2(\tau_{ln}^3 - \tau_{ln}^2), \cdots, (k-1)\,(\tau_{ln}^3 - \tau_{ln}^2)$, the time for each data packet to arrive at the BAN is is $\tau_{ln}^2 + \tau_{ln}^3$, $\tau_{ln}^2 + 2\tau_{ln}^3$, $\tau_{ln}^2 + 3\tau_{ln}^3, \cdots, \tau_{ln}^2 + k\tau_{ln}^3$. Combining the above two situations, the path delay of UE $\rightarrow$ SC $\rightarrow$ BAN can be analyzed from the perspective of the expected average; the packet arrival delay interval is $\max\{\tau_{ln}^2, \tau_{ln}^3\}$, and the initial delay is $\tau_{ln}^2 + \tau_{ln}^3$.

Delay Jitter Analysis

Further, the delay jitter of the link l_{ln}^i can be calculated as

$$\sigma_{ln}^i = \left(1 - PER_{ln}^i\right)(T - \tau_{ln}^i)^2 + PER_{ln}^i\left(1 - PER_{ln}^i\right)(2T - \tau_{ln}^i)^2 + \cdots + (PER_{ln}^i)^{RT} \\ \left(1 - PER_{ln}^i\right)[(RT + 1)T - \tau_{ln}^i]^2 + (PER_{ln}^i)^{RT+1}[(RT + 1)T - \tau_{ln}^i]^2 \tag{4.3}$$

Among them, τ_{ln}^i represents the mean transmission delay of the link l_{ln}^i, PER_{ln}^i represents the packet loss rate, and T represents the one-time transmission delay. Furthermore, Eq. (4.3) describes the fluctuation degree of the transmission delay of the link l_{ln}^i relative to the average delay in the form of mathematical variance (Chaudhry et al. 2020b).

Spreading from the link to the path, for the transmission of the first data packet, since there is no waiting delay, each component link can be regarded as independent of each other, so the initial delay jitter of the path is the sum of the delay jitter of each component link. For the transmission of subsequent data packets, there are two situations of queuing and non-queuing at intermediate nodes. The packet retransmission mechanism makes the calculation of waiting delay more complicated. At this time, each component link can be regarded as interrelated, so the path. The delay jitter should be less than the sum of the delay jitters of each component link.

For simplicity, this paper uses the maximum delay jitter of each component link to approximate the delay jitter of the entire path.

Analyzing the latency and disturbance on the UE → BAN route (where the BAN immediately backhauls UE_{ln}) is straightforward. The cable network's backbone can be reached via a single wireless step. It assumes that the wired connection has no delay jitter, the path wireless. The initial delay jitter and the average delay jitter of the incoming side are both σ_{ln}^{i}. For the UE → SC → BAN path (i.e., the backhaul path where UE_{ln} accesses BAN via SC_1), its initial delay jitter is $\sigma_{ln}^2 + \sigma_{ln}^3$, and the average delay jitter of subsequent packets is max $(\sigma_{ln}^2, \sigma_{ln}^3)$.

Optimization Model Establishments

Basic Backhaul Model

The optimization goal can be written as, based on the delay jitter study above:

$$[X^*, Y^*, Z^*] = \underset{\forall a_{ln}, b_{ln,m}, c_{ln}}{\arg\min} \Big\{ U = \sum\nolimits_{\forall l} \sum\nolimits_{\forall l} (1 - a_{ln}) \big[r.\max\big(\sigma_{ln}^2, \sigma_{ln}^3\big)\big] + a_{ln} \cdot \sigma_{ln}^1 \Big\} \quad (4.4)$$

Among them, U represents the optimization objective function of the basic backhaul model, which can be regarded as the sum of the average delay jitter of all user backhaul paths, X^*, Y^*, and Z^* represent the optimal solutions of X, Y, and Z, respectively, and $r \geq 1$ is the initial delay jitter compensation factor to reflect the effect of the initial delay jitter. In particular, when $\max(\sigma_{ln}^2, \sigma_{ln}^3)$, the average delay jitter of the two types of paths is the same. In this case, UE → BAN with a more negligible initial delay jitter will be selected as the optimal path.

Then, the basic optimization model can be established:

$$\underset{\forall a_{ln}, b_{ln,m}, c_{ln}}{\arg\min} \Big\{ \sum\nolimits_{\forall l} \sum\nolimits_{\forall l} (1 - a_{ln}) \big[r.\max\big(\sigma_{ln}^2, \sigma_{ln}^1\big)\big] + a_{ln}, \sigma_{ln}^1 \Big\} \quad (4.5)$$

$$\text{s. t.} \min\left(\sum_{m=1}^{M_1} b_{ln,m}, a_{ln}\right) = 0, \forall 1, n \quad (4.6)$$

$$\sum_{n=1}^{N_l} b_{ln,m} \leq 1, \forall l, m \quad (4.7)$$

$$\sum\nolimits_{\forall l,n} c_{ln} \leq M_2 \quad (4.8)$$

$$a_{ln} \in \{0, 1\}, \forall l, n \quad (4.9)$$

$$b_{\ln,m} \in \{0, 1\}, \forall l, n, m \tag{4.10}$$

$$c_{\ln} \geq 1, \forall l, n \tag{4.11}$$

Based on Eq. (4.6), UEln uses either the SCBS backhaul (for which the SCBS allocates multiple bandwidths) or the BAN backhaul (for which the SCBS does not assign a channel). According to Eq. (4.7), in order to prevent intra-cell crosstalk, each track within a given cell is only shared by a single user. In Eq. (4.8), M2 is the highest number of channels that can be provided by BAN, so the number of channels allotted by BAN must be less than or equal to M2. Equations (4.9) and (4.10) define the value space of $a_{\ln}$ and $b_{\ln,m}$. Finally, Eq. (4.11) indicates that the BAN bandwidth needs to be allocated no matter how the user is backhauled.

Improved Model 1

The basic model only optimizes the delay jitter and ignores the optimization of a service delay, so the delay interval constraint of the backhaul path of user $\text{UE}_{\ln}$ is added:

$$(1 - a_{\ln})\left[r.\max\left(\sigma_{\ln}^2, \sigma_{\ln}^3\right)\right] + a_{\ln} \cdot \tau_{\ln}^1 \leq \varepsilon_{\ln}, \forall l, n \tag{4.12}$$

Among them, $\varepsilon_{\ln}$ represents the maximum delay constraint to ensure the basic delay requirements of the business. Therefore, an improved model 1 is constructed:

$$\underset{\forall a_{\ln}, b_{\ln,m}, c_{\ln}}{\arg\min} \left\{\sum\nolimits_{\forall l} \sum\nolimits_{\forall l} (1 - a_{\ln})\left[r.\max\left(\sigma_{\ln}^2, \sigma_{\ln}^3\right)\right] + a_{\ln} \cdot \sigma_{\ln}^1\right\} \tag{4.13}$$

$$\text{s.t. } \min\left(\sum_{m=1}^{M_1} b_{\ln,m}, a_{\ln}\right) = 0, \forall 1, \text{n} \tag{4.14}$$

$$\sum_{n=1}^{N_1} b_{\ln,m} \leq 1, \forall l, m \tag{4.15}$$

$$\sum\nolimits_{\forall l,n} c_{\ln} \leq M_2 \tag{4.16}$$

$$(1 - a_{\ln})\left[r.\max\left(\sigma_{\ln,}^2, \sigma_{\ln,}^3\right)\right] + a_{\ln}.\ \tau_{\ln}^1 \leq \varepsilon_{\ln}, \forall l, n \tag{4.17}$$

$$a_{\ln} \in \{0, 1\}, \forall l, n \tag{4.18}$$

$$b_{\ln,m} \in \{0, 1\}, \forall l, n, m \tag{4.19}$$

$$c_{\ln} \geq 1, \forall l, n \tag{4.20}$$

Improved Model 2

When the number of users exceeds the number of available channels on the network (that is, the network is overloaded), the above model will face an unsolvable problem, namely:

$$N = \sum_{l=1}^{L} N_l > M_2 \tag{4.21}$$

At this time, even if $c_{\ln} = 1(\forall \mathrm{l}, n)$, there is still $\sum_{\forall 1,n} c_{\ln} = N > M_2$.

Since there is insufficient BAN route to satisfy all demands, the admittance control system must be triggered, disappointing some users. As for which users are dismissed and how resources are allocated to admit users, an improvement model 2 needs to be established:

$$\arg\min\left\{U + w\left(M_2 - \sum\nolimits_{\forall l,n} c_{\ln}\right)\right\} \tag{4.22}$$

$$\text{s.t. } \min\left(\sum_{m=1}^{M_1} b_{\ln,m}, a_{\ln}\right) = 0, \forall 1, n \tag{4.23}$$

$$\sum_{n=1}^{N_l} b_{\ln,m} \leq 1, \forall l, m \tag{4.24}$$

$$\sum\nolimits_{\forall l,n} c_{\ln} \leq M_2 \tag{4.25}$$

$$(1 - a_{\ln})\left[r.\max\left(\sigma_{\ln}^2, \sigma_{\ln}^3\right)\right] + a_{\ln}.\ \tau_{\ln}^1 \leq \varepsilon_{\ln}, \forall l, n \tag{4.26}$$

$$a_{\ln} \in \{0, 1\}, \forall l, n \tag{4.27}$$

$$b_{\ln,m} \in \{0, 1\}, \forall l, n, m \tag{4.28}$$

$$c_{\ln} \geq 0, \forall l, n \tag{4.29}$$

where ω is the adjustment factor, if ω is small, U is inclined to be optimized; if ω is large, $M_2 - \sum_{\forall l,n} c_{\text{ln}}$ is inclined to be optimized to allocate resources to users as much as possible under the premise of ensuring a solution. Also, if $c_{\text{ln}} = 0$, the user request is denied.

Improved Model Solutions

Modified Model 1 and Modified Model 2 are fundamentally integer programming. To solve the above models quickly, according to their mathematical characteristics, corresponding solving algorithms are designed based on stratification and branch and bound.

Improved Model 1 Solution

Modified Model 1 consists of the Boolean vector X, the Boolean matrix Solution Y, and the number vector Z. This leads to the optimization problem being decomposed into its component parts. First, the initialization process is given as follows:

Initialization:

1. Generate $X = \text{zeros}(1, N)$, $Y = \text{zeros}(N, M_1)$,
2. $Z = \text{ones}(1, N)$
3. Input: W, C, L, N_1, M_1
4. for $b_{\text{ln}} \in Y$, $W_m \in W$
5. $if\left(m = \left(\sum_{l=1}^{l-1} N_l + n\right) \text{mod} M_1\right) || ((\sum_{l=1}^{l-1} N_l + n)/M_1 \in N^*)$
6. then $b_{\text{ln},m} \leftarrow 1$ end if
7. end for
8. for $W_m \in W$, $C_1 \in C$
9. if $\sum_{n=1}^{N_l} b_{ln,m} \geq 2$
10. then $b_{\text{ln},m'} = \text{find}(b_{\text{ln},m} = 1)$; $b_{\text{ln},m'} \leftarrow 0$; $a_{\text{ln}} \leftarrow 1$ end if
11. end for
12. Output: Initial solution X,Y,Z

In the first layer, solve for the vector X. Vector X according to Eq. (4.18) to construct multiple subproblems. Each iteration can obtain an optimal solution to the current optimization problem. Among them, ff_{ln} represents the value of the formula on the left side of Eq. (4.17), and ff_0 represents its minimum value. In the algorithm, f_0 and $\{ f_{ln}\}$ represent the objective function value of the current feasible solution. The first layer of explanation that is, Algorithm 1, is as follows:

Algorithm 1 Algorithm for Computing X Vector
Input: X, Y, Z, $\mathbf{M_2}$, R, RT, PL
Calculate $\mathbf{f_0}$;

for $a_{\ln} \in$ X
if $a_{\ln} = 0$ then
$a_{\ln} \leftarrow 1$; $b_{\ln,m'} = \text{find}(b_{\ln,m} = 1)$; $b_{\ln,m'} \leftarrow 0$;
Calculate $ff_{\ln}$, $f_{\ln}$;
if $(ff_{\ln} \le \varepsilon_{\ln})\&\&(f_{\ln} < f_0)$ then
$f_0 \leftarrow f_{\ln}$;
else $b_{\ln,m'} \leftarrow 1$; $a_{\ln} \leftarrow 0$; end if
end if
end for
Output: optimized value X^*Y, f_0

Matrix Y must be solved in the second layer. Using the first layer's answer, the remaining channels in the cell have been allocated so as to fulfill the algorithm (17). Users who access SCBS get more channels, which will reduce the packet loss rate accordingly. The second layer of the solution that is, Algorithm 2, is as follows:

Algorithm 2 Algorithm for Computing Y Matrix
Input: $\boldsymbol{X^*}$, $\boldsymbol{Y}$, $\boldsymbol{Z}$, $\boldsymbol{W}$, $\boldsymbol{f_0}$, $\boldsymbol{N_l}$, $\boldsymbol{M_2}$, $\boldsymbol{\varepsilon_{\ln}}$, $\boldsymbol{R}$, RT, PL

for $a_{\ln} \in X$
if $a_{\ln} = 0$ then
$b_{\ln,m'} = \text{find}(b_{\ln,m} = 1)$;
for $W_m \in W$
if $(W_m \ne W_{m'})\&\&(\sum_{n'=1}^{N_l} b_{\ln' m} = 0)$ then
$b_{\ln,m} \leftarrow 1$; $b_{\ln,m'} \leftarrow 0$; Compute f_m;
if $f_m < f_0$ then $f_0 \leftarrow f_m$;
else $b_{\ln,m} \leftarrow 0$, $b_{\ln,m'} \leftarrow 1$ end if
end if
end for
end if
end for
for $a_{\ln} \in X$
if $a_{\ln} = 0$ then
while $ff_{\ln} > \varepsilon_{\ln}$
$b_{\ln,m'} = \text{find}(b_{\ln,m} = 1)$;
for $W_m \in W$
if $(W_m \ne W_{m'})\&\&(\sum_{n'=1}^{N_l} b_{\ln' m} = 0)$ then
$b_{\ln,m} \leftarrow 1$; Calculate $ff_{\ln,m}$; $b_{\ln,m} \leftarrow 0$ end if
end for
$ff_{\ln,m^*} = \arg\min(ff_{\ln,m})$; $b_{\ln,m^*} \leftarrow 1$;
end while
end if

end for
for $W_m \in W$, $a_{\ln} \in X$
if $a_{\ln} = 0$ then
Set B_temp = find($b_{\ln,m} = 1$);
if ($b_{\ln,m} \notin$ B_temp)&&($\sum_{n'=1}^{N_l} b_{\ln' m} = 0$) then
$b_{\ln,m} \leftarrow 1$; Calculate $f_{\ln,m}$, $\text{ff}_{\ln,\text{m}}$; $b_{\ln,m} \leftarrow 0$; end if
end if
$[f_{\ln,m^*}] = \arg\min(f_{\ln,m})$;
if ($ff_{\ln,m^*} \leq \varepsilon_{\ln}$)&&($f_{\ln,m^*} < f_0$) then
$f_0 = f_{\ln,m^*}$, $b_{\ln,m^*} \leftarrow 1$ end if
end for
Output: optimized value of Y^*

In this step, solve the matrix Z. After the first and second layers are solved, the current optimization problem becomes a pure integer programming problem. The remaining channels of the BAN are allocated, and one remaining channel is allocated for each traversal. The third layer of the solution that is, Algorithm 3 is as follows:

Algorithm 3 Algorithm for Computing Z Vector
Input: X^*, Y^*, Z, f_0, L, N_1, M_2, $\varepsilon_{\ln}$, r_2, RT, PL

while $\sum_{l=1}^{L} \sum_{n=1}^{N_l} c_{ln} < M_2$
for $c_{\ln} \in Z$
$Z' \leftarrow Z$; $c_{\ln} = c_{\ln} + 1$; compute $f_{\ln}$, $ff_{\ln}$; $Z \leftarrow Z'$;
end for
$[f_{1^*n^*}] = \arg\min(f_{\ln})$;
if ($ff_{1^*n^*} \leq \varepsilon_{\ln}$)&&($f_{1^*n^*} < f_0$) then
$f_0 \leftarrow f_{1^*n^*}$; $c_{1^*n^*} = c_{1^*n^*} + 1$ end if
end while
Output: optimized value of Z^*

The above method for finding a solution can be seen to break down the initial issue into a set of three progressively more difficult challenges iteratively solved according to the characteristics of the solution space. The related problem's optimal solution can be obtained using the branch and bound method, and the iterative solution can gradually converge to the optimal solution of the original problem.

Improved Model 2 Solution

Based on the solution technique of the improved model 1, based on the mathematical characteristics of the enhanced model 2, a three-layer solution technique of the improved model 2 is proposed:

In the first layer, solve the matrix X. Relax (25) and set $\omega = 0$. The solution method is the same as algorithm 1 of the enhanced model 1.

In the second layer, solve matrix Y. The solution process is the same as algorithm 2 of the enhanced model 1.

In the third level, the vector Z must be resolved. It is required to reevaluate the limits of Eq. (4.25) based on the answers found in the first and second layers and to conduct $N-$M2 repetitions. At each step, the person with the largest delay fluctuation in the present optimization outcome is dropped. Algorithm 4 describes the method used to find the answer.

Algorithm 4 Algorithm for Solving Z Vector
Input: X^*, Y^*, Z, L, N_1, M_1, M_2, ω, ε_{ln}, r, RT, PL

1. While $\sum_{l=1}^{L}\sum_{n=1}^{N_l} a_{\text{ln}} + \sum_{l=1}^{L}\sum_{n=1}^{N_l}\sum_{m=1}^{M_1} b_{\text{ln},m} > M_2$ do
2. for $a_{\text{ln}} \in X$
3. if $a_{\text{ln}} = 1$ then $a_{\text{ln}} \leftarrow 0$;
4. Algorithm 1; Algorithm 2;
5. compute f_{ln}; $a_{\text{ln}} \leftarrow 1$;
6. else for $b_{\text{ln},m} \in Y$
7. Set B_temp = find($b_{\text{ln},m} = 1$);
8. for $b_{\text{ln},m} \in$ B_temp then $b_{\text{ln},m} \leftarrow 0$ end for
9. Algorithm 1; Algorithm 2; Calculate f_{ln};
10. for $b_{\text{ln},m} \in$ B_temp then $b_{\text{ln},m} \leftarrow 0$ end for
11. end for
12. end if
13. end for
14. $[f_{1^*n^*}] = \arg\max(f_{\text{ln}})$; $a_{1^*n^*} \leftarrow 0$;
15. $b_{1^*n^*,1} \leftarrow 0$, $b_{1^*n^*,2} \leftarrow 0$, …, $b_{1^*n^*,M1} \leftarrow 0$;
16. end while
17. for $a_{\text{ln}} \in X$
18. if $(a_{\text{ln}} = 0)\&\&(\sum_{m=1}^{M_1} b_{\text{ln},m} = 0)$ then $c_{\text{ln}} \leftarrow 0$ end if
19. end for
20. Output: optimized solution Z^*

Simulation Analysis

The BAN is positioned in the middle of a 500 m * 500 m, and all four are placed evenly at regular intervals. To ensure complete coverage, the SCBS has a typical contact radius of 175 m. Each of the N customers corresponds to one of the N SCBSs, and the N transmission channels are modeled as Rayleigh fading channels. Furthermore, the network's performance will be directly affected by the value of the number of retransmissions RT: a large RT will increase the transmission delay but decrease the packet loss rate, while a small RT will decrease the transmission delay but increase the packet loss rate. To find a happy medium between transmission lag and packet loss in a real-world system, try RT = 5. Table 4.1 shows additional simulation parameters.

Table 4.1 Parameters used in simulation

Parameter	Parameter	Parameter value
α	Free space transfer coefficient	3
n_0^{BAN}	Thermal noise of BAN/(dBm · Hz^{-1})	−174
n_0^{SCBS}	Thermal noise of SCBS/(dBm · Hz^{-1})	−174
Δ_{BAN}	Channel bandwidth allocated by BAN/MHz	20
Δ_{SC}	Channel bandwidth allocated by SCBS/MHz	20
M_2	Number of channels that can be given by BAN	250
P_{UE}	User's transmit power/dBm	7
P_{SC}	Transmit power of SCBS/dBm	27
H	Packet sending rate /(Mb · s^{-1})	100
PL	Packet size/bit	512
r	Initial delay compensation factor	1.1
Ω	Regulator	1000

In this paper, we propose the Improved Model 1-Based Solved Algorithm (IM1SA) and the Improved Model 2-Based Solved Algorithm (IM2SA) as two versions of a model-based solved algorithm for wireless backhaul optimization, and we model their performance using three distinct algorithms to evaluate their effectiveness. WBOASBS (Gu et al. 2018) is the wireless backhaul optimization algorithm for single backhaul scenarios, and it belongs to the first class of algorithms. This approach was developed for a particular kind of communication scenario. (that is, all users access the BAN through SCBS for backhaul). The second category of method is the Wireless Backhaul Optimization method for Static Channel Scenarios (WBOASCS) (Zhang et al. 2020). To optimize channel allocation, the third type of algorithm, WBOABIDJ, uses an average delay jitter index that does not take into account channel dynamics. This algorithm is considered for hybrid backhaul scenarios (which include two types of backhaul methods). All three categories of algorithms are very similar to the one presented in this article, and each one is developed with the help of MATLAB. Delay jitter is used as an efficiency metric to evaluate the aforementioned methods. Jitter in this context refers to the time it takes to implement the outcomes of channel distribution derived from various methods into a working network. The typical user delay fluctuation number is determined.

In the situation of minimal service demand, Fig. 4.2 compares the delay jitter of IM1SA, the other three kinds of algorithms, and the number of users (the number of users is less than M2). Increasing the number of users N causes the delay jitter of the four distinct methods to rise steadily, as shown below for varying values of M1; when the number of users is small, the network load is low, and the network performance is at a better level (that is, the link packet loss rate is standard), at this time, the delay jitter of the same algorithm under different M1 is very close; when the number of users is large, the network load is high, and the network performance deteriorates (that is, the link packet loss rate is high), At this time, the higher M1, the smaller

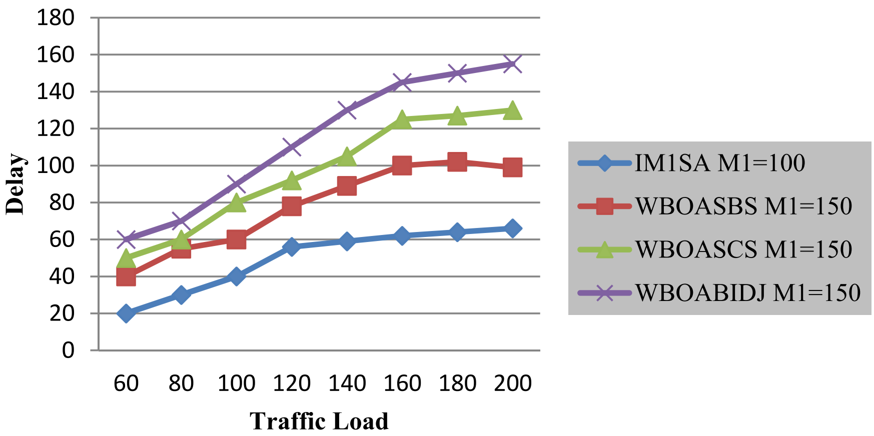

Fig. 4.2 Comparison of delay and jitter of four types of algorithms (low business load)

the delay jitter of the same algorithm; in any case, the delay jitter performance of IM1SA is always optimal (Table 4.2).

The modeling findings for the light traffic burden scenario are not shown in Fig. 4.2. Once the number of users rises above M2, all four kinds of algorithms will be unable to optimize the system; in other words, they will be useless in an overloaded system. As a result, IM2SA is proposed in this article. In the event of a heavy service demand, the delay fluctuation of IM2SA varies as shown in Fig. 4.3. (that is, the number of users is more significant than M2). As the number of users on IM2SA grows, the delay fluctuation will only vary within a narrow range. The IM2SA delay fluctuation decreases as the number of users, N, increases. Admission management and channel allocation can be efficiently executed by IM2SA.

In the case of IM2SA, the delay jitter performance based on IM2SA is always maintained at a certain level without deterioration (Tables 4.3 and 4.4).

Figure 4.4 shows the different results of the network parameter of IM2SA with the number of users in the case of a high service load (that is, the number of users is more significant than M2). It can be seen that the packet delivery ratio, end-to-end delay, and load of IM2SA fluctuates within a specific range with the increase in the number of users N. Given the number of users, the delay jitter of IM2SA shows a downward trend with the rise in M1. IM2SA can effectively carry out admission control and allocate channels reasonably.

Table 4.2 Comparison of delay and jitter of four types of algorithms (low business load)

	60	80	100	120	140	160	180	200
IM1SA M1 = 100	20	30	40	56	59	62	64	66
WBOASBS M1 = 150	40	55	60	78	89	100	102	99
WBOASCS M1 = 150	50	60	80	92	105	125	127	130
WBOABIDJ M1 = 150	60	70	90	110	130	145	150	155

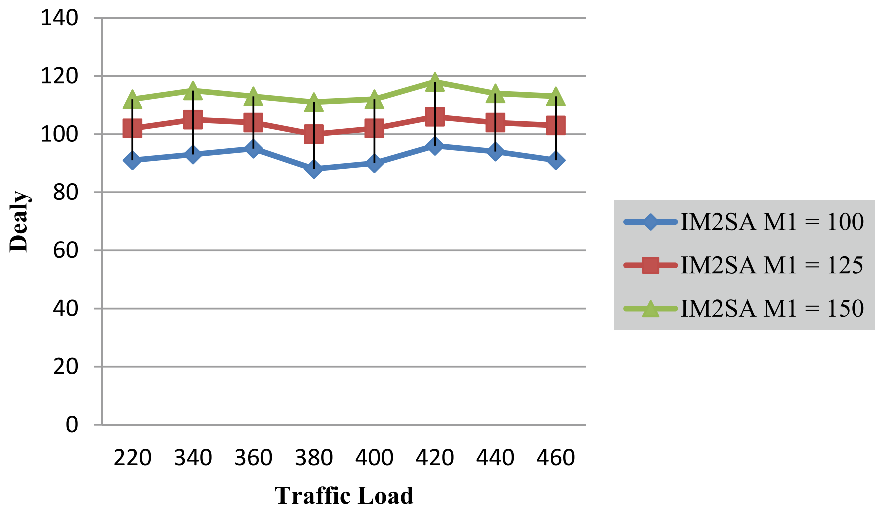

Fig. 4.3 IM2SA delay jitter results (high traffic load)

Table 4.3 IM2SA delay jitter results (high traffic load)

	220	340	360	380	400	420	440	460
IM2SA M1 = 100	91	93	95	88	90	96	94	91
IM2SA M1 = 125	102	105	104	100	102	106	104	103
IM2SA M1 = 150	112	115	113	111	112	118	114	113

Table 4.4 IM2SA evaluation over network parameter

Network scenario	Packet delivery ratio (PDR)	End-to-end delay	Load
IM1SA M1 = 100	78	56	58
WBOASBS M1 = 150	72	68	62
WBOASCS M1 = 150	68	72	74
WBOABIDJ M1 = 150	62	75	80

Conclusions

For 5G dynamic diverse situations, this article suggests an optimization method for wireless backhaul that takes delay uncertainty into account. Backhaul optimization metrics are created, and a fundamental backhaul model is built, based on a methodical

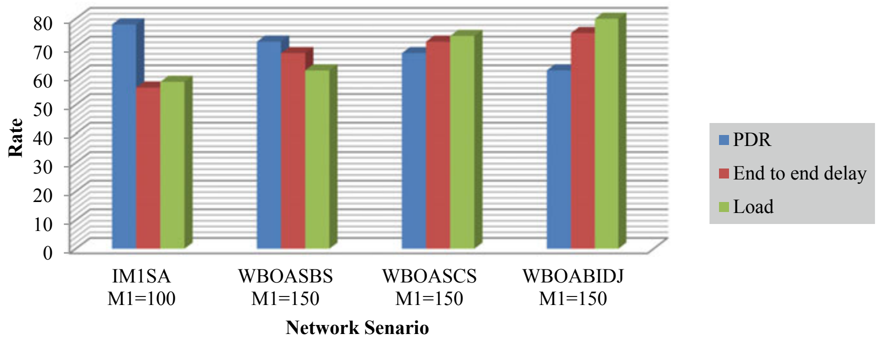

Fig. 4.4 IM2SA evaluation over network parameter

study of service delay and delay instability in active diverse techniques. Additionally, an optimized model 1 and an optimized model 2 are developed from the vantage points of delay optimization and network overflow, respectively, and a hierarchy method is suggested to handle them efficiently. This article uses a program to demonstrate the efficacy of the method.

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