PAPER *Special Section on Wide Band Systems*

Dynamic Resource Assignment Scheme in Mesh-Topology Millimeter-Wave Broadband Entrance Networks

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SUMMARY This paper proposes the dynamic resource assignment (DRA) scheme in the multi-carrier mesh-topology millimeter-wave (MMW) broadband entrance networks. In the DRA scheme, the radio path allocation and the frequency channel assignment techniques are deployed to maximize the network throughput. In the radio path allocation technique, the traffic load is distributed into the appropriate paths. On the other hand, the frequency channel assignment is performed based on the linear programming (LP) method. As the results, the proposed DRA scheme yields higher throughput performance than the conventional scheme using the random frequency channel assignment. In addition, the proposed scheme can guarantee the throughput performance when the number of frequency channels is 36 and the input load is no more than 9 Gbps. Moreover, the proposed scheme can yield the satisfaction sub-optimum throughput with the small computational complexity.

key words: *broadband entrance network, dynamic resource assignment, linear programming, centralized control*

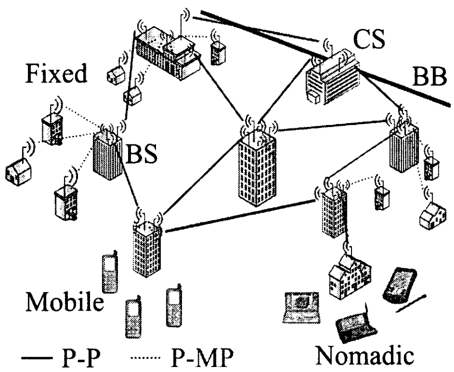

Fig. 1 Millimeter-wave broadband wireless network.

1. Introduction

An explosion in the growth of the multimedia communications is tremendously increasing the demand, and then has motivated extensive researches in new broadband services especially the broadband wireless access (BWA) systems offered a tremendous advantage over the wired technologies such as ADSL (Asynchronous Digital Subscriber Line), CATV (Cable TV) and FTTH (Fiber to the Home) in point of their rapid deployment with low-cost. The BWA industry has matured to the point at which it now has the IEEE Standard 802.16 for second-generation wireless metropolitan area networks [1]–[2]. Fixed wireless access (FWA), one of BWA systems, is expected to play a major role in providing high-speed and flexible services [3]–[4]. In Japan, FWA services at present are provided in the 22, 26 and 38 GHz bands according to the association of radio industries and businesses (ARIB) standards of STD-T58 and STD-T59 [5]. However, according to the tremendous increase of high-speed demand, the new bands should be allocated. As the discussions within WRC (World Radio Conference) 2000, several new bands, e.g., 32, 52 and 55 GHz, have been reserved internationally for the high density fixed service (HDFS) including FWA. In Japan, a new BWA system exploiting 32 GHz band has been developed from today FWA to cope with the rapid growth of demand from now on [6].

As illustrated in Fig. 1, this BWA is developed to provide the seamless broadband Internet access services for the wireless heterogeneous systems including the fixed, nomadic and mobile access services as the entrance network connecting between the base stations (BSs), the center station (CS) and the backbone (BB) network. The concept of the entrance network is similarly investigated in the radio access network (RAN) for the digital enhanced cordless telecommunications (DECT) [7] and the 4G mobile communication [8]. In addition, in order to support the extension of various novel advanced communications, the entrance network should be simple, universal operated and independent of technologies of those systems. Therefore, the non-regenerative repeaters are installed at the BSs in the entrance network because they only convert the frequency band, i.e., the entrance network deals with those systems in the wireless physical layer [9].

With the implementing of links into P-P (Point-to-Point) mesh-topology as the entrance network, system can support the high-speed communication in high-level of service coverage [10] and is flexible in point of that adaptive routing can be implemented to avoid the fell down or traffic-congested links. In addition, with the deployment of millimeter-wave (MMW) band, system will meet the large available bandwidth and the reduced size of electronic components. However, its quality is severely affected by rainfall. Therefore, the concept of making a route detour avoiding a heavy rain zone that causes poor link quality or link outage was proposed in [11] and [12]. Moreover, we proposed the concept of the QoS-based adaptive modulation scheme

Manuscript received February 17, 2004.
Manuscript revised May 15, 2004.
Final manuscript received June 18, 2004.

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to compensate for the rain attenuation in [13]. Notice that in [11]–[13], system used the single-carrier format. However, the multi-carrier format can provide more efficient frequency resource usage and more robust to the traffic change when using the appropriate frequency channel assignment.

Therefore, this paper proposes the dynamic resource assignment (DRA) scheme including the radio path allocation technique and the frequency channel assignment technique to maximize the throughput in network. First, the radio path allocation technique includes the adaptive modulation compensating for the rain attenuation and the traffic load distribution selecting the appropriate path. It is deployed to determine how many frequency channels are necessary for each radio link. Second, the frequency channel assignment technique is deployed to assign a particular set of frequency channels to each radio link. The frequency channel assignment in mesh-topology wireless network was studied in [14]–[16]. References [14] and [15] performed the assignment in autonomous and decentralized manner, which each BS selects its own channels based on the radio statements made in a limited area surrounding the BS and then cause the non-optimum channel assignment. Reference [16] proposed the channel assignment in the centralized control manner by using the simulated annealing algorithm, and simply evaluated the performance in the tree-topology network.

In this paper, we perform the sub-optimum frequency channel assignment in the mesh-topology multi-carrier wireless entrance network with the centralized control manner based on the linear programming (LP) method [17]. Reference [18] studied the channel allocation based on the LP method in the multiuser OFDM (Orthogonal Frequency Division Multiplexing) system which the BS receives the downlink channel information from all users, and using this information to assign a set of subcarrriers (channels) to each user. It is assumed that the reuse of subcarrier by the different users is not allowed. Unlike the system in [18], in the mesh-topology entrance network, the common use of a channel between the different radio links is permitted with taking account of the interference power. That is, if the number of the required frequency channels is more than the number of frequency channels in system, it is preferable that the channel should be commonly used between the little interfered radio links. The frequency channel assignment problem is how to maximize the total throughput in the network.

The remainder of this paper is organized as follows. Section 2 is devoted to describe the system architecture of the MMW broadband wireless network. In Sect. 3, the proposed dynamic resource assignment scheme including the radio path allocation and the frequency channel assignment techniques is presented. Section 4 shows the performance evaluations. Finally, a conclusion is given in Sect. 5.

2. MMW Broadband Wireless Network

The architecture of mesh-topology MMW broadband wireless network is illustrated in Fig. 1. Both P-P and P-MP (Point-to-MultiPoint) technologies are deployed to provide services where P-MP links are providing broadband access services, while P-P links are providing the high-bandwidth supply of the broadband entrance network for the wireless heterogeneous systems including the fixed, nomadic and mobile access services. In addition, the non-regenerative repeaters are installed at the BSs in the entrance network. This is because it should deal with heterogeneous systems in the wireless physical layer to support the extension of various novel advanced systems with ease, i.e., the entrance network becomes simple, universal operated and independent of technologies.

The use of non-regenerative repeating scheme implies that traffic load is transmitted in the physical wireless layer. From this viewpoint, this paper employs the concept of two-plane [12], the IP-based control plane and the physical wireless layer-based traffic transmission plane, as shown in the generalized multiprotocol label switching (GMPLS) [19], the control protocol used to set up paths in the IP network, to manage the physical wireless network connection. This control plane is responsible for both routing and signaling to support dynamic provision and restoration of label-forwarding information, and explicit a route for each connection between source and destination in the whole network.

The path is selected by the path manager in control plane using the proposed traffic load distribution routing algorithm described in Sect. 3.1. The path manager acquires the state including traffic information from each BS by using the routing protocol such as the open shortest path first with traffic engineering extension (OSPF-TE) to generate and receive the opaque link-state advertisements (LSAs) [19]. When the path is discovered, it is assigned as the explicit route, and then the signaling protocol, either the constraint-based routing label distribution protocol (CR-LDP) or the resource reservation protocol with traffic engineering extension (RSVP-TE) [19], is responsible for establishing a forwarding state and reserving resources along the route.

3. Dynamic Resource Assignment

In the dynamic resource assignment, the traffic should be distributed into the suitable radio paths. Next, the necessary frequency channels for each P-P link are determined, and then assigned appropriately.

3.1 Radio Path Allocation

With the deployment of the MMW, the deterioration of radio link quality according to rainfall becomes the large problem. First, in any radio link employing the adaptive modulation, when the rain falls, the modulation level should be shifted down to maintain the quality, i.e., the bit error rate performance, of the radio link. However, when shifting down the modulation level, it requires more frequency channels to transmit the same bit rate and thus may cause more interference to other links then limit the error rate performance

Step 1: Initially, $L = \{a\}$, $D_i = \lambda_{ai}$ and $H_i = h_{ai}$ for all $i \neq a$

Step 2: Find set $K \notin L$ so that $D_K = \min_{i \notin L} D_i$

Step 3: If K has more than one element,

find $k \in K$ so that $H_k = \min_{i \in K} H_i$,

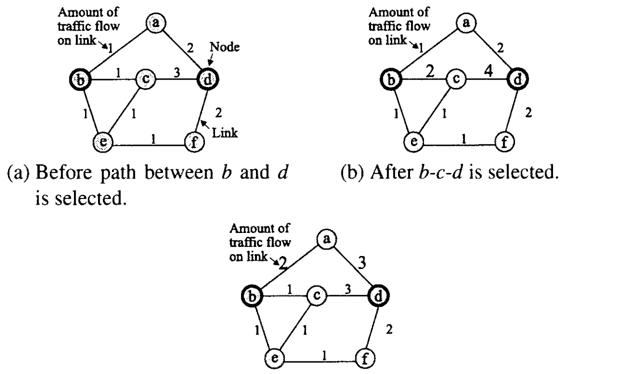
$L := L \cup \{k\}$

If L contains node m, a path is found and the algorithm terminates

Step 4: For all $i \notin L$, set $D_i := \min[D_i, D_k + \lambda_{ki}]$

Step 5: Go to Step 2.

Fig. 2 The minimum shortest path selection algorithm.



(a) Before path between b and d is selected.

(b) After b-c-d is selected.

(c) After b-a-d is selected.

Fig. 3 Example topology.

especially in the case of large traffic load.

Second, the routing considering the traffic load distribution should be performed to maximize the resource utilization efficiency in the network. Since there are the rainfall condition variation and the traffic load variation according to the multimedia communication in the network, the use of the simple shortest path first (SPF) routing algorithm cannot guarantee the performance because it computes the path obliviously to the loading of each link thus it may easily cause the traffic congestion on some links.

Therefore, in order to perform the traffic load distribution efficiently, we propose the minimum shortest path (MSP) selection algorithm. The path with the minimum traffic flow metric will be selected, where the traffic flow metric of path is considered as the maximum amount of traffic from a set of links belonging to that path. If there are multiple paths with the same traffic flow metric, the path with minimum number of hops, i.e., shortest path, will be selected. Notice that, in common, the residual capacity is used as the cost metric in the path selection algorithm. However, in the dynamic resource assignment, the capacity of each radio link is not fixed and decided yet, hence we use the amount of traffic flow as the cost metric in the path selection. Moreover, this algorithm performs the path selection by the priority of distance between source and destination, i.e., the nearer source-destination pair has more priority to be performed.

Let us consider a graph $G = (N, A)$ with number of nodes N and number of links A, in which each link (i, j) is assigned λ_{ij} as the amount of traffic flow. Given any path $p = (a, b, c, \ldots, l, m)$, the traffic flow metric is defined as $\lambda_p = \max(\lambda_{ab}, \lambda_{bc}, \ldots, \lambda_{lm})$, and the number of hops is defined as h_p. The MSP algorithm performs the path selection as shown in Fig. 2. Let D_i and H_i be the estimated traffic flow metric and number of hops of path form node a to node i. Step 2 finds all minimum amount of traffic flow paths. If there are more than one path found, Step 3 chooses the one with minimum number of hops.

For example, let us consider the connection request of traffic flow between b and d in the topology shown in Fig. 3. We assume that numbers illustrated in Fig. 3 denote the amount of traffic flow on each link normalized by the amount of requested traffic flow between b and d. Before the path between b and d is selected, the amount of traffic flow is indicated as illustrated in Fig. 3(a). By applying the SPF, paths with minimum hops, i.e., (b, a, d) and (b, c, d), become the candidates, and then one of these 2 paths is randomly selected. If the path (b, c, d) is selected, the traffic load will congest on link cd as shown in Fig. 3(b). On the other hand, by applying the MSP, the path (b, a, d) will be selected and then the amount of traffic flow on each link becomes as shown in Fig. 3(c).

Finally, the necessary frequency channels for each P-P link are determined.

3.2 Frequency Channel Assignment

This paper proposes the sub-optimum frequency channel assignment based on the linear programming (LP) method [17] to assign a particular set of frequency channels (subcarriers) to each link in order to maximize the total throughput in the network. Note that the throughput denotes the successful received traffic rate.

In the LP-based channel allocation in the multiuser OFDM system, different users are not allowed to use the same subcarrier [18]. On the other hand, in the mesh-topology entrance network, the common use of a channel between the different radio links is permitted with taking an account of the interference power. That is, if the number of the required frequency channels is more than the number of frequency channels in system, it is preferable that the channel should be commonly used between the little interfered radio links. Moreover, the frequency channel must be assigned so that two paths that use a same physical radio link never use the same frequency channel on that radio link.

Let us first define the parameters as follows:

N_f : Number of frequency channels,

N_t : Number of total frequency channels, i.e., traffic slots, required by all radio links in network,

N_s : Number of assigned frequency channels in any assignment round,

N_{ra} : Number of remaining assigned traffic slots.

The proposed frequency channel assignment is performed as detailed in the flowchart shown in Fig. 4. When the number of the total required traffic slots N_t is equal or less than the number of frequency channels N_f, the fre-

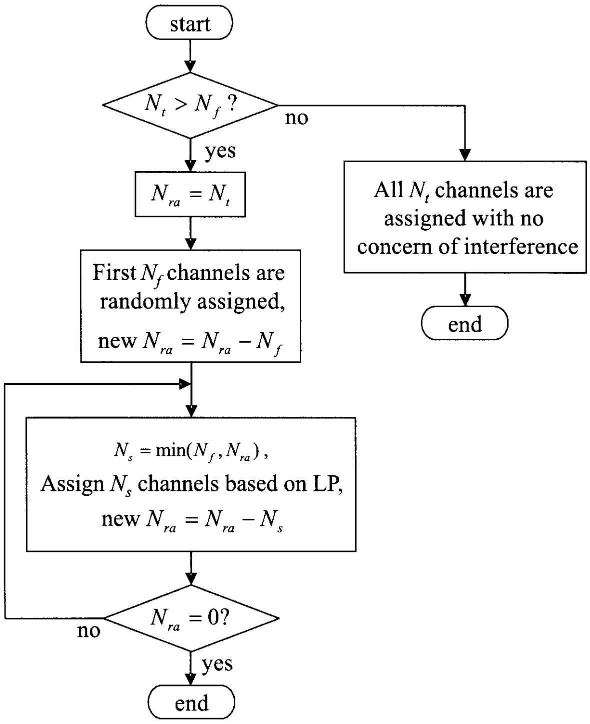


Fig. 4 The frequency channel assignment flowchart.

quency channel assignment can be done simply because there are enough frequency channels to assign one by one with no concern of any interference. On the other hand, when the N_t is more than N_f, there is the common use of some channels between the different radio links, hence the appropriate frequency channel assignment taking account of the interference should be considered.

At the beginning, the number of remaining assigned traffic slots N_{ra} is set to be the N_t. The N_f frequency channels are randomly assigned with no concern of any interference to the first N_f traffic slots. Note that this algorithm gives the priority of assignment to the slots of link that has more probability to interfere other radio links, i.e., the farther link from the CS has more priority to be assigned in the case of uplink communication. Since the N_f channels are assigned, the N_{ra} is subtracted by N_f. After that, if the N_{ra} is still more than the N_f, only the N_f slots can be assigned based on the LP method considering the interference to maximize the total throughput in this assignment round, and the N_{ra} is subtracted by N_f. after the assignment in this round. On the other hand, if N_{ra} is less than the N_f, all the remaining N_{ra} slots can be assigned at once, based on the LP method. As mentioned above, we perceive that the number of assigned frequency channels in any assignment round N_s can be written as $\min(N_f, N_{ra})$. The assignment is performed until all traffic slots are assigned, i.e., $N_{ra} = 0$.

Next, we describe the details of the LP-based frequency assignment method in any assignment round. Let us define $c_{i,j}$ as the indicator of allocating the jth frequency channel to the ith traffic slot. The indicator $c_{i,j}$ is expressed as

$$c_{i,j} = \begin{cases} 1, & \text{if the } j\text{th frequency channel is} \\ & \text{assigned to the } i\text{th traffic slot,} \\ & i = 1, 2, \ldots, N_s, \;\; j = 1, 2, \ldots, N_f \\ 0, & \text{otherwise} \end{cases} . \tag{1}$$

The $r_{i,j}$ denotes the throughput normalized by the channel bandwidth [bps/Hz], i.e., the frequency utilization efficiency, of the ith traffic slot using the jth frequency channel, and is defined as

$$r_{i,j} = (\log_2 M) \cdot \left(1 - PER_{i,j}\right), \tag{2}$$

$$PER_{i,j} = 1 - \sum_{k=0}^{l_m} \binom{l_p}{k} \cdot \left(BER_{i,j}\right)^k \cdot \left(1 - BER_{i,j}\right)^{l_p - k}, \tag{3}$$

$$BER_{i,j} = \frac{2}{\log_2 M} \cdot \left(1 - \frac{1}{\sqrt{M}}\right) \cdot \mathrm{erfc}\left(\sqrt{\frac{3 \cdot \gamma_{i,j}}{2 \cdot (M-1)}}\right), \tag{4}$$

where $PER_{i,j}$ and $BER_{i,j}$ respectively denote the packet error rate and bit error rate of case the ith traffic slot using the jth frequency channel, M is the level of modulation (M-ary quadrature amplitude modulation, M-QAM), l_p is the packet length, l_m is the maximum tolerable error bits in packet, erfc(.) is the complementary error function, and $\gamma_{i,j}$ is the carrier-to-noise-plus-interference power ratio (CNIR) of the ith traffic slot using the jth frequency channel. Note that the antenna used in our system is the directional rectangular horn with the antenna front-to-back ratio of α_{fb}. It is assumed that in the case of the idealized optimum, the interference from the other links is negligible except the overreached interference, and the α_{fb} is set to be ∞. Moreover, the frequency channel assignment in the case of the idealized optimum is performed for all N_t channels at a time.

The frequency channel assignment problem can be formulated as follows:

Find a set of $c_{i,j}$ to maximize

$$\sum_{j=1}^{N_f} \sum_{i=1}^{N_s} r_{i,j} \cdot c_{i,j} \tag{5}$$

subject to

$$\sum_{j=1}^{N_f} c_{i,j} = 1 \quad \forall i \in \{1, \ldots, N_s\}, \tag{6}$$

$$\sum_{i=1}^{N_s} c_{i,j} \leq 1 \quad \forall j \in \left\{1, \ldots, N_f\right\}, \tag{7}$$

where N_s is the number of assigned traffic slots in any assignment round, and is equal or less than N_f. The constraint (6) ensures that the one frequency channel is assigned to each traffic slot, and the constraint (7) ensures that each frequency channel can be assigned to only one traffic slot in any assignment round.

After the problem is solved, we obtain the allocation indicator matrix **C** which has entries of 0 and 1, and dimension of $\left[N_s \times N_f\right]$.

For example, as illustrated in Fig. 5, consider the 6 frequency channels network ($N_f = 6; j = 1, 2, \ldots, 6$), where the number of total frequency channels (traffic slots) required by all radio links in network N_t is 10 (5 links which requires 2 frequency channels each). Assume the first 6 frequency channels are assigned to the first 3 links ($l = 1, 2, 3$) as (2, 4), (3, 6), (1, 5), and then the remaining assigned traffic slots $N_{ra} = 10 - 6 = 4$. Hence in the next LP-based assignment round, the $N_s = \min(6, 4) = 4$ slots will be assigned. After the assignment to first 3 links, the assigned frequency channels yield that the frequency utilization efficiency profiles of the fourth link ($l = 4$) are 2.0, 1.9, 1.8, 1.9, 2.0 and 1.8 bps/Hz, respectively to the frequency channels $j = 1, 2, \ldots, 6$. On the other hand, the frequency utilization efficiency profiles of the fifth link ($l = 5$) are 1.9, 1.6, 1.7, 1.6, 1.9 and 1.7 bps/Hz, respectively to the frequency channels $j = 1, 2, \ldots, 6$.

Since each link requires 2 frequency channels for its own, the frequency utilization efficiency profiles of each link are duplicated to form the matrix **R** whose entries are the frequency utilization efficiency profiles, $r_{i,j}$, as

$$\mathbf{R} = \begin{bmatrix} 2.0 & 1.9 & 1.8 & 1.9 & 2.0 & 1.8 \\ 2.0 & 1.9 & 1.8 & 1.9 & 2.0 & 1.8 \\ 1.9 & 1.6 & 1.7 & 1.6 & 1.9 & 1.7 \\ 1.9 & 1.6 & 1.7 & 1.6 & 1.9 & 1.7 \end{bmatrix}. \tag{8}$$

By using Eqs. (5)–(7), the allocation indicator matrix is solved, and then becomes

$$\mathbf{C} = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix}. \tag{9}$$

So we can perceive that the frequency channel assignment in this example is that the fourth link uses frequency channels $j = 2$ and $j = 4$, and the fifth link uses frequency channels $j = 1$ and $j = 5$.

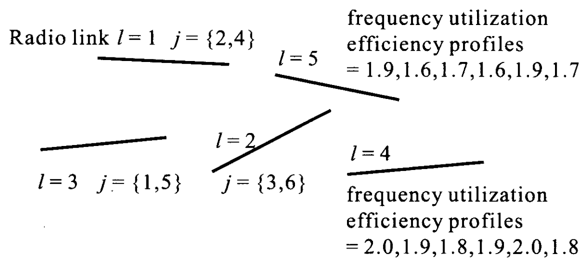
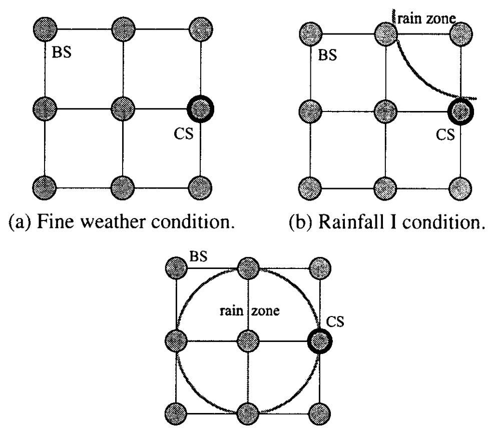


Fig. 5 Example topology.

4. Performance Evaluations

The analysis model is illustrated in Fig. 6. The eight base stations (BSs) and one center station (CS) each, arranged into the 3 × 3 square mesh-topology, are established connections with the 3 km length P-P links as the non-regenerative wireless entrance network, and are under the line-of-sight (LOS) and the adaptive white Gaussian noise (AWGN) environments. This square mesh-topology is considered in order to evaluate the performance in the severe interference condition. Assume the network 6(a) is under the fine weather condition, the network 6(b) is under the rainfall I (rain falls at the upper right corner of network) condition, and the network 6(c) is under the rainfall II (rain falls at the center of network) condition. The rain rate in the rain zone is assumed to be the heavy flat rate of 45 mm/h. This causes the rain attenuation of 10 dB/km as the calculation from the power-law relationship by the ITU-R recommendation [20]. The specific rain attenuation $\gamma = k \cdot R^{\alpha}$ [dB/km] where R is the rain rate in mm/h, $k = 0.221$ and $\alpha = 1.003$ for 32 GHz band [21]. Table 1 lists the parameters used in the calculations. With the use of parameters shown in Table 1, under the constraint to achieve the BER of 10^{-4}, the link margin for rain attenuation, interference and noise accumulation in the 256 QAM, 64 QAM, 16 QAM and QPSK formats are 38.6, 44.6, 50.6 and 57.6 dB, respectively.

Let us define the throughput performance as the successful received traffic rate. If the number of error bits of the received packet, whose length is 1500 Bytes (l_p), is no more than 2 bits (l_m), it will be successfully received, and unsuccessfully received in otherwise. The throughput performance of case using the proposed DRA scheme is compared to that of case using the conventional scheme. The proposed scheme uses the LP-based frequency channel assignment. On the other hand, the conventional scheme uses the random frequency channel assignment. Note that the both schemes apply the MSP routing algorithm. Moreover, we classify the conventional scheme into two schemes as



(a) Fine weather condition. (b) Rainfall I condition. (c) Rainfall II condition.

Fig. 6 Analysis models.

Table 1 Parameters used in calculations.

Carrier frequency	f_c	32 GHz
Bandwidth	BW	720 MHz
Number of frequency channels (Channel bandwidth)	N_f (B_f)	12 (60 MHz), 24 (30 MHz), 36 (20 MHz), 48 (15 MHz)
Transmitted power	P_T	30 dBm
Antenna gain	$G(o)$	42 dBi
Antenna front-to-back ratio	α_{fb}	15, 30 dB
Noise figure	F	8 dB
Atmosphere absorption factor	γ_0	0.11 dB/km
Packet length	l_p	1500 Bytes
Max. tolerable error bits in packet	l_m	2 bits

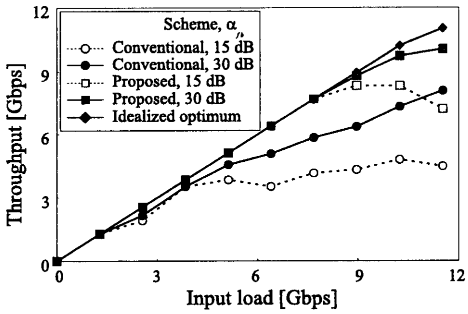
whether using the adaptive modulation technique or not. The conventional I scheme denotes that the fixed modulation is applied, meanwhile, the conventional II scheme denotes that the adaptive modulation is applied. Note that the modulation levels used in the proposed and the conventional II schemes are 256/64/16 QAM and QPSK formats. On the other hand, the modulation used in the conventional I scheme is fixed as 256 QAM format. Only in the case of fine weather condition, both conventional schemes will give the same performance because the conventional II scheme will use the maximum level of modulation of 256 QAM format as in the conventional I scheme.

Let us first evaluate the throughput performance when the number of frequency channels N_f is 36. For the sake of simplicity, the calculations are done in the case of uniform traffic. In addition, the throughput performance of case of the idealized optimum is also compared. It is assumed that in case of the idealized optimum, the frequency channel assignment is performed for all N_t channels at a time, the interference from the other links is negligible except the over-reached interference, and the α_{fb} is set to be ∞. The results of throughput performance versus input load are shown in Fig. 7.

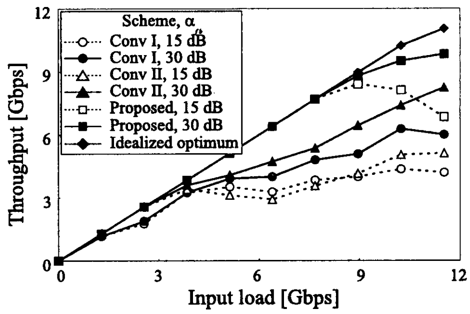
From Fig. 7(a), in the case of fine weather condition, since conventional I and conventional II schemes give the same performance so we simply call these 2 schemes as the conventional scheme in this figure. When the antenna front-to-back ratio α_{fb} is 15 dB, we can observe that the throughput of the conventional scheme becomes saturated if the input load exceeds 4 Gbps. Meanwhile, the throughput of the proposed scheme first increases and reaches a peak at the input load of 9 Gbps and then starts to decrease a little if the input load increases further. On the other hand, when the α_{fb} is 30 dB, it is obvious that the conventional scheme offers quite good throughput, but less than that of the proposed DRA scheme. In addition, we can see that the proposed scheme yields almost the same throughput performance as that of the idealized optimum.

Comparing to the case of the antenna front-to-back ratio α_{fb} of 30 dB, the case of the α_{fb} of 15 dB is under more severe interference condition because the one radio wave is more affected by the inverse direction propagated interference wave. When the input load becomes more than 9 Gbps, the number of total frequency channels required by all radio links in network becomes large then causes lots of interference. With the use of the antenna with the α_{fb} of 15 dB, the interference condition becomes more severe then the received packet tends to be more unsuccessfully received. Hence the throughput degradation becomes appeared. On the other hand, the use of the antenna with the α_{fb} of 30 dB can alleviate the effect of interference even when the input load becomes more than 9 Gbps.

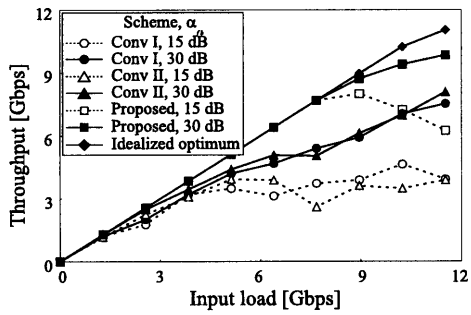
From Fig. 7(b), in the case of rainfall I condition, when the α_{fb} is 15 dB it is clear that the conventional I and II schemes yield almost the same throughput. This is because although the adaptive modulation technique in the conventional II scheme is expected to improve the throughput performance, but it also leads to a more number of frequency channels to transmit the same traffic bit rate and hence causes more severe interference condition especially in this case of the α_{fb} of 15 dB, and thus the throughput improvement becomes insignificant. We also observed that the proposed scheme outperforms the conventional I and II schemes. Moreover, when the input load exceeds 9 Gbps,



(a) Fine weather condition.



(b) Rainfall I condition.



(c) Rainfall II condition.

Fig. 7 Throughput performance versus input load (N_f = 36).

the throughput degradation of the proposed scheme in this case is more than the case of fine weather condition.

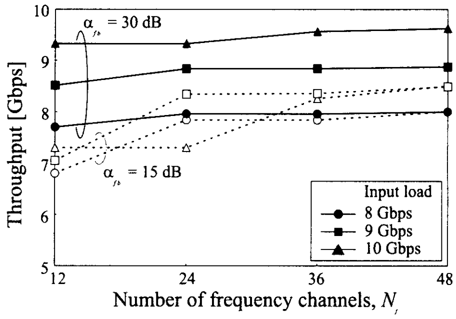
In contrast, when the α_{fb} is 30 dB, the conventional I scheme yields the throughput degradation in the rainfall I condition compared to the fine weather condition. This is because the radio link quality is deteriorated by the rain attenuation. Moreover, it is obvious that the conventional II scheme yields the little improved throughput compared to that of the conventional I scheme because of the more link margin by using the adaptive modulation technique. However, it quite degrades the throughput when compared to the proposed scheme.

From Fig. 7(c), in the case of rainfall II condition, it is obvious that the conventional I and II schemes yield almost the same throughput in both cases of the α_{fb} are 15 and 30 dB. We can see that, when the α_{fb} is 30 dB, the conventional I scheme gives the better throughput in the rainfall II condition compared to the rainfall I condition. This is because the rain falls at the center of network then the interference becomes weak, and thus the throughput becomes a little degraded when compared to the fine weather condition. On the other hand, the conventional II scheme yields a little degraded throughput in the rainfall II condition compared to the fine weather condition, which is almost the same as that of the conventional I scheme. In addition, the proposed scheme more outperforms the conventional I and II schemes as the input load increases, except when the α_{fb} is 15 dB and the input load exceeds 9 Gbps. Moreover, we can see that when the input load exceeds 9 Gbps, the throughput degradation of the proposed scheme compared to the idealized optimum in the rainfall II condition is more than that in the fine weather condition.

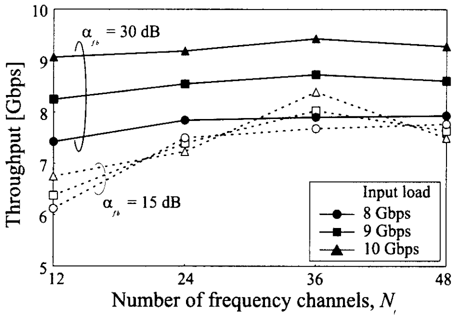
Figure 8 shows the throughput performance versus number of frequency channels N_f when using the proposed DRA scheme. It is clear that when the α_{fb} is 15 dB, the throughput performance is dependent on the number of frequency channels and the weather condition. In the case of fine weather condition, the N_f of 12 and 24 yield the degraded throughput performance since interference becomes larger as decreasing the N_f. Meanwhile, in the case of rainfall I and rainfall II conditions, the N_f of 36 yields the best throughput performance compared to the other cases of N_f (12, 24 and 48) when the input load is more than 9 Gbps. This is because when the N_f is 48, the traffic load was distributed then causing lots of inverse direction propagated waves. Hence, we obtained the results opposite to those we have intended. In contrast, when the α_{fb} is 30 dB, since the effect of interference can be well mitigated, the throughput performance is almost the same in all cases of the number of frequency channels and the weather condition.

Therefore, from Fig. 7 and Fig. 8, we can perceive that the proposed DRA scheme can guarantee the throughput performance even in the case of the α_{fb} of 15 dB when the N_f is 36 and the input load is less than 9 Gbps.

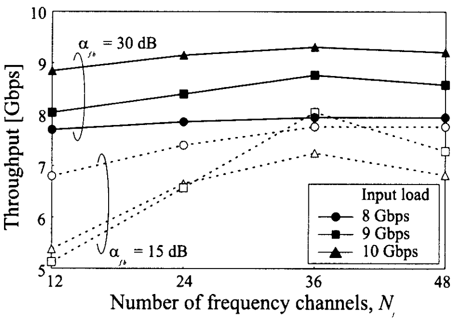
Finally, we examine the computational complexity of the proposed LP-based frequency channel assignment scheme and the case of the idealized optimum. As revealed



(a) Fine weather condition.



(b) Rainfall I condition.



(c) Rainfall II condition.

Fig. 8 Throughput performance versus number of frequency channels.

in Sect. 3.2, the N_f denotes the number of frequency channels, the N_t denotes the number of total frequency channels required by all radio links in network. The computational complexity of the idealized optimum case is $\left(N_f\right)^{N_t}$. On the other hand, the computational complexity of the proposed scheme can be expressed as $\lfloor N_t/N_f \rfloor \cdot \left(N_f\right)^2 + rem\left[N_t/N_f\right] \cdot N_f$, where $rem\,[a/b]$ denotes the remainder obtained when dividing a by b. Therefore, we can perceive that the proposed scheme outperforms the idealized optimum case more efficiently as the N_t increases. Since the computational complexity of the proposed scheme is small, it is expected to dynamically track and perform the resource assignment well. Therefore, we can perceive that the proposed DRA scheme can yield the satisfaction sub-optimum throughput as shown in Fig. 7 with the small computational complexity.

5. Conclusion

This paper has proposed the DRA scheme including the radio path allocation and the LP-based frequency channel assignment techniques for the P-P mesh-topology MMW broadband entrance networks. As the results, the proposed DRA scheme yields higher throughput performance than the conventional scheme using the random frequency channel assignment. In addition, the proposed DRA scheme can guarantee the throughput performance when the number of frequency channels is 36 and the input load is no more than 9 Gbps. Moreover, the proposed DRA scheme can yield the satisfaction sub-optimum throughput with the small computational complexity.

Acknowledgement

This paper is partially supported by the Grants-in-Aid for Scientific Research (B) No.14350202, from the Japan Society for the Promotion of Science.

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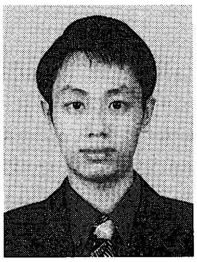

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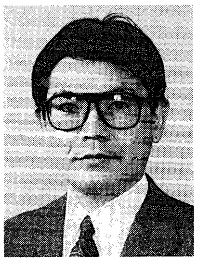

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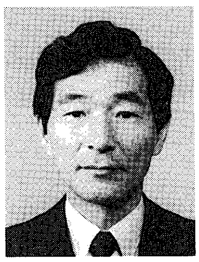

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