OFDMA WMNs(Wireless Mesh Networks) Resource Allocation for Heterogeneous Services

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Abstract

Wireless mesh networks (WMNs) based on Orthogonal frequency division multiple access (OFDMA) is a promising technique for high-speed data transmissions and wide-coverage. To guarantee each user's communication demand, the resource allocation is indispensable. This study mainly focuses on the resource allocation in OFDMA Wireless Mesh Network uplink systems for heterogeneous services. First, we investigate the minimization of wireless resources for real time traffic while satisfying users' demands. Second, we investigate the throughput maximization for non-real time traffic.

Ⅰ. Introduction

As demand for broadband mobile communication increases, mobile communication systems are expected to support various types of services simultaneously. These systems must support reliable and high-rate data transmission. For these reasons, the orthogonal frequency division multiple access (OFDMA) scheme, based on orthogonal frequency division multiplexing, has emerged as one of the prime multiple access schemes for broadband wireless networks.

In wideband transmissions over multi-path fading channels, inter-symbol interference (ISI) is a major problem, as it inhibits high-rate data communications. However, in OFDMA systems, each subcarrier is assigned exclusively to a single client, and intra-cell interference is eliminated by using an orthogonal frequency. This aspect of the OFDMA can solve the ISI problem. This advantage makes the OFDMA a promising system for future wireless communication systems.

In the future wireless communication systems, another aspect of wireless communication system is a broadband accessibility. To extend the broadband access to the last mile, the deployment and research isssues of the wireless mesh networks (WMNs) has attracted more and more attentions recently. WMN is connected to the Internet via a mesh router (MR), and which consists of a group of mesh clients (MCs) that can potentially relay each other's packets to/from the MR[1].

In wireless communication systems, resource allocation is an important issue. Depending on the resource allocation scheme, the system can maximize throughput or enforce fairness flexibly. Allocating subcarriers and power in the OFDMA WMNs system has been investigated recently. In [2], based on the assumption of clustered networks, summation of utility function maximization

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problem was dealed with minimun requirements of each nodes. In [3], distributed algorithms for joint end-to-end rate control and wireless resource allocation were proposed. An utility function was used for determining rate and power allocation phase. However, these studies did not include various services simultaneously. As a result, unfair and inefficient assignments can result. Some clients may not be able to obtain their desired throughput while others may obtain throughput far beyond their needs. According to the various types of services, clients have mutually exclusive demands. In OFDMA systems, the demands of one client can conflict with the demands of another client. In this situation, it is necessary to develop an efficient formulation and algorithm to minimize conflicting client demands while including various types of services for each clients.

In this paper, we propose a refined formulation for subcarriers and power allocation problem with considering heterogeneous services. Revised and relaxed Linear Programming (LP) formulation of multi-radio multi-channel WMNs resource allocation problem is presented.

Ⅱ. System Model & Assumptions

In this paper, we consider an OFDMA WMN that consist of $N+1$ nodes which are compromised of one mesh router and N mech clients. Fig. 1 illustrates the network model considered in this paper. The set of nodes is denoted by $N=\{0,1,\dots,N\}$, where node 0 represents the MR that delivers traffic between the MCs and the Interent. Some MCs, dentoed by set O, are located in the one-hop communicatino range of the MR whreas the others, denoted by set $N1(=N-O)$, are located outside the MR's one-hop communication range and need to access the Internet via multihop. Assuming that there are K subcarriers in the system, subcarriers are assumed to be orthogonal to each other. Assuming that each subcarrier has a narrow bandwidth, each subcarrier experiences a flat fading within its bandwidth. In addition, it is assumed that the channel state of each client's information is transmitted by an appropriate control channel so that the MR can obtain perfect knowledge of the channel state information of its neighborhood. In addition, MR is assumed to have unlimited power level and the connection between MR and internet has sufficiently large data rates. In [1], this assumption is not unreasonable by using separate channel. In this system, each MCs demands can be classified into two types : realtime traffics and non-realtime traffics. Lastly, table 1 presents the notation used in this paper.

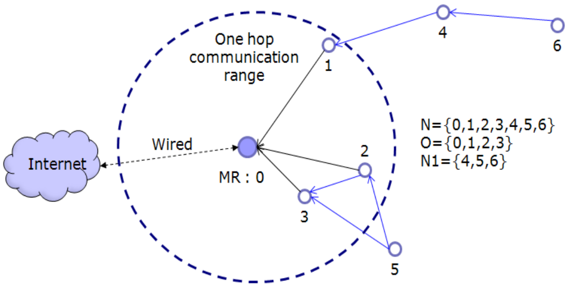

Fig. 1 System model

item	description
N	Nodes set
O	Nodes set within one hop communication range
$N1$	N-O
S	Subcarriers set
r_i	Realtime traffic demand of MCi
nr_i	Nonrealtime traffic demand of MCi
L	Set of all links
P_i	Power of MCi
$I(l)$	Interfering links set of link l
$Lo(i)$	Set of links which is orginated from MCi
$Lt(i)$	Set of links which is terminated at MCi
$ne(i)$	Number of transceiver of MCi

Table. 1 Notations.

Detailed explanation of $I(1)$ is as follows. Given a link l, the interfering links set of link $l(i\leftrightarrow j)\in L$ is given by:

$$I(l) = all\ links\ incident\ on\,(i's \neq ighbors \setminus j) \\ \cup\ all\ links\ incident\,on\,(j's \neq ighbors \setminus i)$$

For example, in the Fig. 2 MC_2 has its interfering links set as $I(3) = \{1, 2, 3, 4, 5\}$ where each elements of interfering links set represent a link which is same as $i \leftrightarrow j$ $(ex, 2 = (0 \leftrightarrow 2))$.

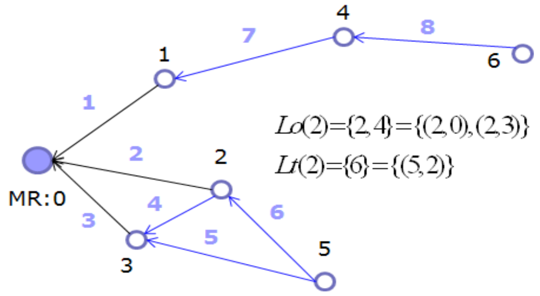

Fig. 2 Link example

Simillarly, $Lo(i)$ and $Lt(i)$ is explained by example of MC_2 in Fig. 2.

We must consider a throughput of each MCs seperately since multihop nature. The throughput of each MCs can be divided by two groups. The one is source-destination pairs which can communicate directly and the other is source-destination pairs which must need other nodes' cooperation for communication. In an OFDMA system, it is optimal to allocate a subcarrier to only one client [4]. Due to the frequency selective fading, each client experiences different channel gains for different subcarriers. Assuming AWGN noise with variance N_0, it can be claimed that each client experiences equal noise power over all subcarriers. For client i and subcarrier j, the signal-to-noise-ratio (SNR) is as follows:

$$g_{ij} = \frac{|H_{ij}^2|}{B/N \bullet N_0} \quad (1)$$

where H_{ij} is the channel gain of client i for subcarrier j and B is a total bandwidth used in the OFDMA system.

Based on the Shannon capacity formula for the Gaussian channel, the throughput of a single client, who can communicate with his destination directly, can be written as follows:

$$T_i = \frac{B}{N} \sum_{l \in Lo(i)} \sum_{k \in S} x_l^k \log(1 + p_l^k g_l^k) \quad (2)$$

where $x_l^k \in \{0, 1\}$ is the channel allocation index such that if subcarrier k is assigned to client l and equals 0 otherwise. p_i^j is the power allocated to subcarrier j when it is allocated to client i. Otherwise, the throughput of a single client, who needs cooperation of neighborhood, is defined as follows:

$$T_i = \frac{B}{N} \bullet \frac{\sum_{l \in Lo(i)} \sum_{k \in S} x_l^k \log_2(1 + p_l^k g_l^k)}{2} \quad (3)$$

Ⅲ. Formulation

In this section, we suggest novel formulation of WMN resource allocation problem which supports heterogeneous services. The resource allocation strategy is applied differently to real-time traffic and non-real time traffic. Supporting real time traffic with minimum resource and maximization of non-real time traffic with remain resource are key concepts of resource allocation strategy.

Let x_l^k denote the binary notation corresponding to the links, such that $x_l^k = 1$ if link l is assigned subcarrier k. Also, P_l^k is the power of sending node on link l which uses subcarrier k. g_l^k is the channel gain of link l which uses subcarrier k.

With the above notation, we can define the throughput of node i as:

$$T_i = \begin{cases} \dfrac{B}{N} \bullet \sum_{l \in Lo(i)} \sum_{k \in S} x_l^k \log_2(1 + p_l^k g_l^k) \\ ;\forall i : one\ hop \\ \dfrac{B}{N} \bullet \dfrac{\sum_{l \in Lo(i)} \sum_{k \in S} x_l^k \log_2(1 + p_l^k g_l^k)}{2} \\ ;\forall i : m\mu lti\ hop \end{cases} \quad (4)$$

which is based on shannon capacity.

First, we consider the resource allocation problem for real time traffic. Formulation of the wireless resource minimization in WMNs is as follows:

$$
\begin{aligned}
& Min\ \alpha \frac{\sum_{l \in L} \sum_{k \in S} p_l^k}{\sum_{i \in N} P_i} + \beta \frac{\sum_{l \in L} \sum_{k \in S} x_l^k}{K} \\
& s.t \sum_{i \in I(l)} x_i^k = 1;\ \forall k \in S,\ \forall l \in L \\
& \quad T_i \geq r_i;\ \forall i \in N \\
& \quad \sum_{l \in Lo(i) \cup Lt(i)} \bigvee_{k \in S} x_l^k \leq ne(i)\ \forall i \in N \quad (5) \\
& \quad \sum_{l \in Lo(i)} \sum_{k \in S} p_l^k \leq P_i;\ \forall i \in N \\
& \quad x_l^k \in \{0, 1\};\ \forall l, k \\
& \quad p_l^k \geq 0;\ \forall l, k
\end{aligned}
$$

The power of link and the number of subcarriers are considered as wireless resources. The objective function for real-time traffic problem is as follows:

$$Min\ \alpha \frac{\sum_{l \in L} \sum_{k \in S} p_l^k}{\sum_{i \in N} P_i} + \beta \frac{\sum_{l \in L} \sum_{k \in S} x_l^k}{K} \quad (6)$$

where, α and β are weights. Now, we discuss the constraints for solving the minimization problem. The first constraint enforces all links in $I(l)$ not to share the same subcarrier:

$$\sum_{i \in I(l)} x_i^k = 1;\ \forall k \in S,\ \forall l \in L \quad (7)$$

For satisfying users' demands, the second constraint ensures that the realtime traffic demand of MC_i is less than or equal to the throughput of MC_i.

$$T_i \geq r_i;\ \forall i \in N \quad (8)$$

The third constraint is related to network interface card (NIC) limitations. The number of links from the set $\{x_l^k : l \in Lo(i) \cup Lt(i), k \in S\}$ is limited by the number of transceiver of MC_i.

$$\sum_{l \in Lo(i) \cup Lt(i)} \bigvee_{k \in S} x_l^k \leq ne(i);\ \forall i \in N \quad (9)$$

Our next constraint is the power constraint. The sum of power which is originated from MC_i must not exceed the power of MC_i.

$$\sum_{l \in Lo(i)} \sum_{k \in S} p_l^k \leq P_i;\ \forall i \in N \quad (10)$$

With the objective function of minimizing wireless resources under constraints (7), (8) and (9), the proposed problem can be regarded as a mixed integer problem (MIP) which is in NP-hard problem. Since solving the MIP is hard, revising formulation (5) can be an efficient approach to reduce time complexity of solving (5).

By deleting the binary variable x_l^k of the throughput function T_i since, T_i is a non linear function, throughput function of node i can be a linear form. Instead of deleting variable x_l^k, adding new constraint (11) to enforce consistency is required. If link l uses subcarrier k, the power of link l which is originated from MC_i is less than or equal to the power of MC_i.

$$
\begin{aligned}
& p^k_{l:\, \forall l \in Lo(i)} \leq P_i \bullet x^k_{l:\, \forall l \in Lo(i)} \quad (11) \\
& ;\ \forall i \in N,\ \forall k \in S
\end{aligned}
$$

The constraint (9) contains logical OR operation. For revising this constraint, we introduce a variable z_l which is related to links of MC_i to eliminate logical OR operation. The variable z_l should be larger than or equal to x_l^k. Also, the summation of z_l should be less than or equal to the number of transceiver of MC_i. By doing this, (12) and (13) can be alternative constraints for (9).

$$\sum_{l \in Lo(i) \cup Lt(i)} z_l \leq ne(i);\ \forall i \in N \quad (12)$$

$$x_l^k \leq z_l;\ \forall k \in S, l \in Lo(i) \cup Lt(i) \quad (13)$$

Finally, formulation for the wireless resource minimization is as follows:

$$
\begin{aligned}
& Min\ \alpha \frac{\sum_{l\in L}\sum_{k\in S} p_l^k}{\sum_{i\in N} P_i} + \beta \frac{\sum_{l\in L}\sum_{k\in S} x_l^k}{K} \\
& s.t \sum_{i\in I(l)} x_l^k = 1 ; \forall k \in S, \forall l \in L \\
& \quad T_i \geq r_i ; \forall i \in N \\
& \quad \sum_{l\in Lo(i)\cup Lt(i)} z_l \leq ne(i) ; \forall i \in N \\
& \quad x_l^k \leq z_l ; \forall k \in S, l \in Lo(i) \cup Lt(i) \qquad (14) \\
& \quad \sum_{l\in Lo(i)}\sum_{k\in S} p_l^k \leq P_i ; \forall i \in N \\
& \quad p^k_{l:\forall l\in Lo(i)} \leq P_i \bullet x^k_{l:\forall l\in Lo(i)} \\
& \quad ; \forall i \in N, \forall k \in S \\
& \quad x_l^k \in \{0,1\} ; \forall l, k \\
& \quad p_l^k, z_l \geq 0 ; \forall l, k
\end{aligned}
$$

Second, we consider the resource allocation problem for non-real time traffic. To consider non-real time traffic, changing the objective function of formulation (14) into maximization of throughput is sufficient to satisfy resource allocation strategy. After then, formulation of resource allocation problem for non-real time traffic is as follows:

$$
\begin{aligned}
& Max \sum_{i\in N} T_i \\
& s.t \sum_{i\in I(l)} x_i^k = 1 ; \forall k \in S, \forall l \in L \\
& \quad \sum_{l\in Lo(i)\cup Lt(i)} z_l \leq ne(i) ; \forall i \in N \\
& \quad x_l^k \leq z_l ; \forall k \in S, l \in Lo(i) \cup Lt(i) \qquad (15) \\
& \quad \sum_{l\in Lo(i)}\sum_{k\in S} p_l^k \leq P_i ; \forall i \in N \\
& \quad p^k_{l:\forall l\in Lo(i)} \leq P_i \bullet x^k_{l:\forall l\in Lo(i)} \\
& \quad ; \forall i \in N, \forall k \in S \\
& \quad x_l^k \in \{0,1\} ; \forall l, k \\
& \quad p_l^k, z_l \geq 0 ; \forall l, k
\end{aligned}
$$

By relaxing the binary variable x_l^k, the proposed formulation (14) can be regarded as a LP and problem in LP has polynomial time algorithms. In addition, among solutions which are derived from simplex or ellipsoid method, first order optimality conditions for (5) can reduce computational time for checking optimal solutions. However, the proposed formulation (14) is not a convex programming since integer variable x_l^k. Therefore, global optimality is not guaranteed by applying Karush-Kuhn-Tucker necessary condition[5]. Although, by applying KKT necessary condition, enumeration time for checking integer optimal solution can be reduced. KKT necessary condition for proposed formulation is as follows:

$$
\begin{aligned}
& \alpha \frac{1}{\sum_{i\in N} P_i} + \sum_{i\in N} \left(\frac{B}{N} - \frac{g_l^k}{1+p_l^k g_l^k}\right) \bullet \mu_i + \sum_{i\in N} \varphi_i \\
& \qquad + \sum_{i\in N} \gamma_i \geq 0 ; \forall l, \forall k \\
& \{\alpha \frac{1}{\sum_{i\in N} P_i} + \sum_{i\in N} \left(\frac{B}{N} - \frac{g_l^k}{1+p_l^k g_l^k}\right) \bullet \mu_i + \sum_{i\in N} \varphi_i \\
& \qquad + \sum_{i\in N} \gamma_i \} \bullet p_l^k = 0 ; \forall l, \forall k \\
& \beta \bullet \frac{1}{K} + \lambda_k + \sum_{i\in N} \pi_i + \sum_{i\in N} (-P_i) \bullet \gamma_i \geq 0 \\
& \qquad ; \forall l, \forall k \\
& \{\beta \bullet \frac{1}{K} + \lambda_k + \sum_{i\in N} \pi_i + \sum_{i\in N} (-P_i) \bullet \gamma_i\} \bullet x_l^k \\
& \qquad = 0 ; \forall l, \forall k \\
& \sum_{i\in N} \xi_i + \sum_{i\in N} \pi_i \geq 0 \qquad (16) \\
& \left\{\sum_{i\in N} \xi_i + \sum_{i\in N} \pi_i\right\} \bullet z_l = 0 \\
& \mu_i, \varphi_i, \gamma_i, \pi_i, \xi_i \geq 0 \\
& (\gamma_i - T_i) \bullet \mu_i = 0 ; \forall i \in N \\
& \left(\sum_{l\in Lo(i)}\sum_{k\in S} p_l^k - p_i\right) \bullet \varphi_i = 0 ; \forall i \in N \\
& \left\{p^k_{l;\forall l\in Lo(i)} - P_i \bullet x^k_{l;\forall l\in Lo(i)}\right\} \bullet \gamma_i = 0 ; \forall i \in N \\
& (x_l^k - z_l) \bullet \pi_i = 0 ; \forall l, \forall K, \forall i \in N \\
& \left(\sum_{l\in Lo(i)\cup Lt(i)} z_l - ne(i)\right) \bullet \xi_i = 0 ; \forall i \in N
\end{aligned}
$$

Ⅳ. Future Works

In this paper, a refined formulation of subcarrier and power allocation problem for minimizing real time demands and maximizing non-real time demands in the OFDMA WMN is proposed. However, just brief estimation for time complexity is not enough to demonstrate effectiveness of our proposed formulation. Simulations for presenting computational complexity of our formulation must be shown while varying the real time demands of each clients in our future works. In addition, there are several more problems to solve. In our proposed formulation, nodes which are in one hop communication range are susceptible to be a bottleneck. Also, proposed formulation is based on the centralized management of resource. However, decentralized algorithms are more appropriate for the flexibility and accessibility.

Ⅵ. Reference

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