ABSTRACT
Due to the requisite of multi-channel communications for high-speed data transmissions, power allocation for opportunistically exploiting fading wireless channels, and packet scheduling for quality-of-service provisioning, joint power-frequency-time resource allocation is indispensable. In this paper, we propose a low-complexity intra-cluster resource allocation algorithm, taking power allocation, subcarrier allocation, and packet scheduling into consideration. Numerical results demonstrate that our algorithm is close to optimal, and that our optimality-driven resource allocation algorithm outperforms a greedy algorithm, achieving higher resource utilization and better performance compromise among throughput, packet dropping rate, and packet delay.

Categories and Subject Descriptors
C.2.1 [Computer-Communication Networks]: Network Architecture and Design—Wireless communication

General Terms
Algorithms

Keywords
Quality-of-service (QoS) provisioning, resource allocation, wireless mesh network

1. INTRODUCTION
The wireless mesh networking has emerged as a promising technology for future broadband wireless access, supporting ubiquitous communications and mobile computing [1,2]. Generally, wireless mesh networks (WMNs) consist of wireless gateways, mesh routers, and mesh clients, organized in a multi-tier hierarchical architecture [2]. Recently, the wireless mesh networking has been attracting a plethora of attentions from academia and industry.

In literature, pure random medium access is shown to perform poorly in multi-hop networks. Concerning the capacity of a wireless network with random access, the throughput of a node decreases with the number of wireless nodes [3]. The implication behind these dispiriting results is noteworthy that a node should only communicate with nearby nodes, thereby favoring clustering. Besides, the resource allocation should not be random but governed in an orderly manner so as to improve system performance [4]. In a cluster, collision-free scheduling is feasible, where a clusterhead collects the requests and allocate the corresponding resources (i.e., power, timeslots, and frequency channels) to its cluster members, guaranteeing various QoS demands. The resource allocation can be carried out in a hybrid centralized-distributed fashion (i.e., centralized intra-cluster and distributed inter-cluster resource allocation). In this paper, we focus on resource allocation in a cluster for a mesh backbone.

The problem of subcarrier-bit-power allocation for orthogonal frequency division multiplexing (OFDM) systems has been investigated in [5,6] with respect to the physical layer. In [5], a Lagrangian-based approach is employed to solve the primal optimization problem, achieving better power efficiency. However, the high complexity of the proposed algorithm impedes the ease of practical implementation. Some work (e.g., [6]) attempts to propose lower-complexity schemes. Time scheduling, however, is not addressed properly, which is vital in a practical medium access control (MAC) scheme for QoS provisioning and/or fairness enhancement [7]. As regards the packet scheduling, most of the proposed work either envisages the MAC layer only without taking the wireless channel characteristics into account [8] or does not fully utilize the channel information for the design of resource allocation schemes [9]. In this paper, we propose a low-complexity intra-cluster resource allocation algorithm, taking power allocation, subcarrier allocation, and packet scheduling into consideration. The result obtained from our algorithm is close to the optimal one, verified through numerical analysis. Further, computer simulations show that our optimality-driven resource allocation algorithm outperforms the greedy algorithm by utilizing radio resources more efficiently and providing better performance compromise among throughput, packet dropping rate, and packet delay.

The remainder of the paper is organized as follows. System model is discussed in Section 2. The problem formulation of joint power-frequency-time resource allocation is presented in Section 3. Performance evaluation is given in Section 4. Finally, conclusion is drawn in Section 5.

2. SYSTEM MODEL
We consider a clustered wireless mesh network with an
3. JOINT POWER-FREQUENCY-TIME RESOURCE ALLOCATION

With the OFDM physical layer, to support multimedia applications (e.g., voice, video, and data), subcarrier allocation over the frequency domain is necessary to grant diverse transmission rates. By assigning different subcarriers to different nodes, simultaneous transmissions are fostered, potentially increasing system capacity. Since different frequency bands experience different channel fading characteristics, power allocation with respect to channel conditions is proven to be crucial for QoS provisioning on multi-channel communications. In order to effectively and efficiently support multimedia services with QoS assurance in the MAC layer, bandwidth reservation and hence packet scheduling over the time domain is imperative. In consequence, the joint power-frequency-time resource allocation is vital.

There are various constraints associated with the resource allocation. At each node, the sum of the transmit power on the allocated subcarriers is bounded by a maximum power constraint. In the subcarrier allocation, applying time division multiple access (TDMA) over a subcarrier is more advantageous than all-at-once transmissions [10]. As a result, each subcarrier can only be allocated to one transmission link in a cluster. Different traffic types require different packet transmission rates. For example, voice packets require a constant rate requirement, video traffic has a variable rate with minimum rate, mean rate, and maximum rate requirements, while data traffic is usually treated as a background traffic whose source rate is dynamic. In our problem formulation, we only take the rate requirement of these three traffic types in the coming frame, if any, into account. Variable-rate packet transmissions (i.e., data and video traffic) are to be handled by MAC-layer packet scheduling (to be discussed). For the sake of simplicity, the achievable transmission rate is computed using the Shannon capacity formula. With the above constraints, the objective of our joint power-frequency-time resource allocation is to optimize the system performance which can be system throughput, fairness, or tradeoffs among several system performances (e.g., [11]). Here, we employ the well-known utility maximization framework to abstract the objective.

3.1 Problem Formulation

For the power-frequency-time resource allocation problem, we first start by formulating an optimization problem for the whole network. With the help of node clustering, the network optimization problem can be reduced to a cluster optimization problem.

**Problem Formulation:** Consider the following network optimization problem (NOP):

\[
\max_{a, p} \left\{ \sum_{m=1}^{M} U_m(R_m(a, p)) \right\}
\]

subject to \( R_m(a, p) \geq R_{th}^a, \forall m \)

\( p_{m,n} \geq 0, \forall m, n, l \)

\( \sum_{n=1}^{N_k} p_{m,n} \leq P_{\text{max}}, \forall m, l \)

\( a_{m,n} \in \{0, 1\}, \forall m, n, l \)

where \( R_m(a, p) = \sum_{l=1}^{L} \sum_{n=1}^{N_k} s_{m,n} \eta \left( 1 + \frac{G_{mn,n}^a a_{m,n}^p}{\sigma \sum_{k \neq m} G_{mk,n}^a a_{m,n}^p + \eta} \right) \),

\( U_m(.) \) is the utility function of the \( m \)th link, \( R_m(a, p) \) represents the actual aggregate transmission rate of the \( m \)th link over a frame with \( a = [a_{m,n}]_{M \times N \times L} \) and \( p = [p_{m,n}]_{M \times N \times L} \).

\( d_{m,n} \) is the indicator of allocating the \( n \)th subcarrier to the \( m \)th link on the \( l \)th timeslot, \( p_{m,n} \) is the transmit power over the \( n \)th subcarrier of the \( m \)th link’s transmitter on the \( l \)th timeslot, \( G_{mk,n}^a \) is the channel gain from the \( k \)th link’s transmitter to the \( m \)th link’s receiver over the \( n \)th subcarrier on the \( l \)th timeslot, \( \sigma \) is the cross-correlation factor between any two signals, i.e., \( \sigma \in [0, 1] \), \( \eta \) is the background noise power, \( R_{th}^a \) is the minimum required rate of the \( m \)th link, \( P_{\text{max}} \) is the maximum power constraint of the \( m \)th link’s transmitter, \( M \) is the number of active links in the whole mesh network, \( N \) is the total number of subcarriers, and \( L \) is the number of timeslots (i.e., DATA slots) in a frame. We assume that effective frequency reuse is in place with the aid of node clustering. Then, the NOP can be reduced into the following cluster optimization problem (COP):

\[
\max_{a, p} \left\{ \sum_{m=1}^{M_c} U_m(R_m(a, p)) \right\}
\]

subject to \( R_m(a, p) \geq R_{th}^a, \forall m \)

\( p_{m,n} \geq 0, \forall m, n, l \)

\( \sum_{n=1}^{N} p_{m,n} = P_{\text{max}}, \forall m, l \)

\( \sum_{m=1}^{M} a_{m,n} = 1, \forall l, n \)

\( a_{m,n} \in \{0, 1\}, \forall l, n \)
where \( R_m(a, p) = \sum_{i=1}^{Lc} \sum_{n=1}^{Ne} a^i_{m,n} R^i_{m,n} \),
\[ a^i_{m,n} = \frac{Lc}{Nc} \]
\[ I_m \] is the interference power at the \( n \)th subcarrier, \( M_e \) is the number of active links in the \( c \)th cluster, \( Ne \) is the number of subcarriers allocated to the \( c \)th subcarrier, and \( Le \) is the number of timeslots in a frame for the \( c \)th cluster. In this work, we assume that \( I_m \) is not a function of \( p^i_{m,n} \), \( \forall m, n, l \), in the COP, and we do not consider the coupling effect among clusters. Thus, increasing power can always increase the rate on a subcarrier and hence the utility. The original power constraint (4) is changed into (9).

### 3.2 Problem Complexity

The complexity (hardness) of our COP is as follows.

**Proposition 1.** The COP is an NP-hard problem.

Proof. We prove the NP-hardness by reducing the NP-complete number partitioning problem (denoted by PARTITION) [12] to the COP. We consider the special case of the COP by fixing the power allocation and letting \( M_e = 2 \), \( r^1_{m,n} = r^2_{m,n} = r^i_{m,n} \), \( \forall m, n, l \), and the “size” of the \( n \)th subcarrier at the \( l \)th timeslot is \( r^i_{m,n} \).

Since each subcarrier can only be allocated to one link at any timeslot (i.e., \( a^i_{m,n} + a^i_{m,n} = 1, \forall n, l \)), the solution to this special-case problem is exactly the same as that of the PARTITION problem. In other words, the PARTITION problem can be polynomially transformed into the special-case problem, and vice versa. Since the PARTITION problem is NP-complete, the special-case problem is also NP-complete. Further, the above special-case problem can be generalized by the COP. Thus, the COP is an NP-hard problem.

### 3.3 Resource Allocation Algorithm

In general, solving the COP requires exponential time complexity [13]. To make the problem more tractable, the most commonly used technique is to relax the integer constraints (11) into

\[ a^i_{m,n} \geq 0, \forall m, n, l. \]  

(12)

To investigate the (necessary) conditions for optimality of the solution, consider the following Karush-Kuhn-Tucker (KKT) conditions of the relaxed problem:

\[ -\left[ U_m'(R_m(a, p)) + \beta_m \right] \ln \left( 1 + g^i_{m,m,n} \right) = a^i_{m,n} - \lambda_i, \forall m, n, l \]  

(13)

\[ -\left[ U_m'(R_m(a, p)) + \beta_m \right] \frac{a^i_{m,n} \ln \left( 1 + g^i_{m,m,n} \right)}{1 + g^i_{m,m,n} \gamma_{m,m,n}} = \lambda_i, \tau_{l,m,n}, \forall m, n, l \]  

(14)

\[ R_m(a, p) \geq R^d_m, \forall m \]  

(15)

\[ \sum_{m=1}^{M_e} a^i_{m,n} = 1, \forall m, n, l \]  

(16)

\[ \sum_{n=1}^{Ne} \sum_{m=1}^{M_e} \gamma_{m,m,n} = P^\max_m, \forall m, l \]  

(17)

\[ \beta_m \left( R^d_m - R_m(a, p) \right) = 0, \forall m \]  

(18)

\[ \gamma_{m,m,n} \ln \left( 1 + g^i_{m,m,n} \right) = 0, \forall m, n, l \]  

(19)

\[ a^i_{m,n} \gamma_{m,m,n} \ln \left( 1 + g^i_{m,m,n} \right) = 0, \forall m, n, l \]  

(20)

\[ a^i_{m,n} \gamma_{m,m,n} \ln \left( 1 + g^i_{m,m,n} \right) \geq 0, \forall m, n, l \]  

(21)

\[ \beta_m \geq 0, \forall m \]  

(22)

where \( \beta_m \), \( \gamma_{i,m,n} \), \( \lambda_i \), and \( \alpha_{i,m,n} \) are the Lagrange multipliers for the constraints (7), (8), (9), (10), and (12), respectively. Combining (13) and (20), we have

\[ \lambda_i = U_m'(R_m(a, p)) \left( 1 + g^i_{m,m,n} \gamma_{m,m,n} \right), \forall m, n, l. \]  

(23)

Assume \( R_m(a, p) \neq R^d_m \), then \( \beta_m = 0 \). Therefore, the necessary condition for \( a^i_{m,n} \) being positive is

\[ \lambda_i = U_m'(R_m(a, p)) \left( 1 + g^i_{m,m,n} \gamma_{m,m,n} \right), \forall m, n, l. \]  

(24)

Notice that \( \lambda_i \) can be interpreted as an upper bound of \( U_m'(R_m(a, p)) \left( 1 + g^i_{m,m,n} \gamma_{m,m,n} \right) \) which represents the marginal increase in \( U_m(R_m(a, p)) \) when the \( n \)th subcarrier is allocated to the \( m \)th link on the \( l \)th timeslot (i.e., \( a^i_{m,n} = 1 \)).

Based on the above observation, the criterion of subcarrier allocation can be deduced as follows; for each timeslot \( l \) and each subcarrier \( n \), choose \( m^* \) such that

\[ m^* = \arg \max_{m} \left\{ U_m'(R_m(a, p)) \left( 1 + g^i_{m,m,n} \gamma_{m,m,n} \right) \right\} \]  

(25)

and set \( a^i_{m^*,n} = 1 \). For a given subcarrier assignment, the optimal power allocation is obtained via utility-based water-filling [14]. In fact, the criteria of optimal subcarrier allocation and optimal power allocation are coupled. To reduce the computational complexity, our resource allocation first fixes the power allocation, invokes subcarrier allocation based on the criterion given in (25), reallocates the subcarriers until all the system constraints are met, and then performs utility-based water-filling for power allocation. The detailed procedure is as follows:

**Step 1:** For each user \( m \), equally distribute the transmit power over all \( N_e \) subcarriers on each timeslot \( l \) (i.e., \( p^i_{m,n} = P^\max / N_e, \forall l \)).

**Step 2:** For each timeslot \( l \) and each subcarrier \( n \), allocate the \( n \)th subcarrier according to (25). Repeat until all subcarriers are allocated over all timeslots in the next frame.

**Step 3:** Since the initially obtained resource allocation may not satisfy all the constraints in (7), subcarrier reallocation is needed. Subcarrier reallocation should result in only a small decrease in the total utility while satisfying all the QoS constraints. Let \( M_e \) be the set of unsatisfied links. Consider the following cost function of reallocating a subcarrier to the \( j \)th link instead of the originally assigned \( j \)th link:

\[ \epsilon_{j,n} = \frac{1}{U_j(R_j(a, p)) - U_j(R_j(a, p)) \left( 1 + g^j_{m,m,n} \right)} \]  

\[ \forall j \in M_e. \]  

(26)

The cost \( \epsilon_{j,n} \), a product of two terms, represents the likelihood of reallocating the \( n \)th subcarrier to the \( j \)th link instead of the originally assigned \( j \)th link. The first term in (26) measures the decrease in the total utility for subcarrier swapping. The smaller the change in the total utility, the larger the value of the first term, to maintain the objective function as large as possible.

The second term indicates the tendency of satisfying the QoS requirement of the \( j \)th link if the \( n \)th subcarrier is reallocated to it. The larger the second term, the more likely the QoS requirement of the \( j \)th link can be met. The cost function is basically the combined effects of both terms. Therefore, choose the subcarrier with the maximum cost, i.e., \( j^* = \arg \max_{j \in M_e} \epsilon_{j,n} \). If
the QoS constraints (7) for the \( i \)th link are not violated, perform subcarrier swapping by setting \( a_{i,r,n}^+ = 1 \) and \( a_{i,r,n}^- = 0 \). Repeat this step until all the subcarriers and the timeslots have been searched.

**Step 4:** For each timeslot \( l \), perform utility-based water-filling for power allocation on each link.

Regarding the practicality of our proposed resource allocation, the time complexity of our proposed algorithm is of the order of \( O(L_c M_c N_c) \) only, leading to low computational cost and hence facilitating practical implementation.

In terms of medium access, we consider a simple MAC protocol to illustrate the notion of packet scheduling. Each node estimates the traffic load by averaging the rate requirement over a fixed estimation window (e.g., 100ms) on a regular basis. In the control slot, the clusterhead collects the traffic demand from its cluster members by polling them periodically. Then, the clusterhead runs the proposed algorithm and announces the resource allocation decision in the next beacon slot. For those timeslots and subcarriers allocated to a particular node (or link), they are reserved for packet transmissions in the DATA slots until the next polling. To streamline QoS provisioning, service differentiation is essential. It can be achieved through packet prioritization, meaning that a higher-priority packet is served before a lower-priority one. The priority of voice packets and video packets is related to the performance of their packet dropping rates. The higher the packet dropping rate, the higher the priority of the packets associated with that flow. After gathering the transmission requests, the clusterhead grants the requests of those higher-priority packets first, facilitating QoS provisioning. In other words, our QoS provisioning strategy for the real-time traffic is contingent on the packet dropping rate.

### 4. PERFORMANCE EVALUATION

We consider a cluster with several wireless nodes randomly located in a 1km x 1km coverage area. We assume that the routing is predetermined so that the transmission source and destination pair of an incoming packet is known in advance. The background noise is assumed to be AWGN with zero mean and standard deviation \( 10^{-12} \)W, and the co-channel interference is assumed to follow the Gaussian distribution with zero mean and standard deviation \( 10^{-10} \)W. The maximum power constraint of each node is 8mW. We consider a frequency-selective physical wireless channel, which is modeled by the (uncorrelated scattering) tapped delay model with 10 channel taps. The root mean square delay spread \( (\sigma_{rms}) \) is assumed to be 1µs. We further assume that the channel amplitude follows an exponential power-delay profile. Let \( \tau \) denote the delay of a wireless signal. The channel amplitude and channel phase are randomly generated according to a complex zero-mean Gaussian distribution with variance \( \exp(-\tau/\sigma_{rms}) \) and a uniform distribution over \([0, 2\pi]\), respectively. The operating frequency band and the maximum transmission rate over each subcarrier are assumed to be 1.9 – 2.0GHz and 1Mbps, respectively. We further assume that efficient equalization is in place so that an inter-symbol interference can be completely eliminated. We adopt the path loss model for the terrain category A (i.e., hilly/moderate-to-heavy tree density) suggested in [15]. The objective function given in (6) is chosen to maximize the system throughput (i.e., \( U_m(R_m(a,p)) = R_m(a,p) \)).

**4.1 Numerical Analysis**

First, we compare the result obtained from our proposed resource allocation algorithm with the optimal solution. The optimal solution is acquired by an exhaustive search, where complexity is of at least the order of \( O((L_c M_c N_c)^{N_c}) \). We consider three active links and one DATA slot in a cluster, i.e., \( M_c = 3 \) and \( L_c = 1 \), and choose their rate demands as \( R_d^1 = 9 \)Kbps, \( R_d^2 = 0 \)Kbps, and \( R_d^3 = 3 \)Kbps. The numerical results are plotted in Fig. 1. The performance of our proposed resource allocation algorithm (with and without optimal power allocation) is close to the optimal solution. However, the performance gap between our algorithm with optimal power allocation and that with uniform power allocation becomes obvious with the number of subcarriers. The rationale is similar to the concept of multi-user diversity. The more the subcarriers, the more the variation of channel conditions across the subcarriers. Power allocation by water-filling can opportunistically make use of such a variation, thereby resulting in better performance. However, we observe that in the high signal-to-noise-ratio (SNR) regime (i.e., large \( P^{max}_m \)), the performance difference between optimal power allocation and uniform power allocation is small, for the impact of channel variation becomes less significant. Due to the low complexity and the near-optimal performance, our resource allocation algorithm can be a good candidate for implementation in practice.

**4.2 Simulation**

The system performance of our proposed algorithm is further evaluated via extensive simulations. In the simulations, we consider that the wireless system is synchronized. There are 1 beacon slot, 1 control slot, and \( L_c \) DATA slot(s) in a frame. The duration of a timeslot is 5ms, and hence the duration of a frame is \( 5(L_c + 2) \)ms. The polling is done in every 100ms. Both the polling and the beacon packet transmission are assumed to be error-free. We perform the simulations for 1,000 runs and average the results, where each simulation run sustains 10,000 frames.

Three different traffic models are considered:

- **Voice Traffic** – Voice traffic can be modeled as a two-state ON-OFF model. In the ON state, a fixed-size

![Figure 1: Comparison of the results obtained from our proposed resource allocation algorithm and the optimal solution acquired via an exhaustive search.](image-url)
packet arrives at a constant rate, whereas in the OFF state, no packet is generated. The duration of an ON period and that of an OFF period both follow an exponential distribution.

- **Video Traffic** – Video traffic is modeled as an ON-OFF model in our simulations. In the ON state, a video source generates a continuous packet (frame) stream at a constant inter-arrival time. Following the GBAR source model suggested in [16], different incoming packets have different packet sizes, generating a variable-rate traffic. In the OFF state, no packet is generated. The durations of both an ON period and an OFF period both follow an exponential distribution.

- **Data Traffic** – In general, data traffic is usually assigned the lowest priority. In our simulations, we consider a bursty data traffic model, where data packet arrivals follow a Poisson distribution with rate 50 packets/second, and the packet size (X) follows a Weibull distribution, i.e., \( X \sim \text{Weibull}(2, 2) \). We assume that data traffic does not have any rate requirements. Data packets can be transmitted whenever there are excess resources left in the network.

The parameters of the voice and video traffic models are summarized in Table 1. To mimic the mixed type of traffic in the mesh backbone, we assume that there is a voice source, a video source, and a data source residing at every node. Higher-priority packets are to be served first. If packets are of the same priority, they are served in a first-come-first-serve manner.

The performance measurements are defined as follows:

- Throughput for the background data traffic – the total number of successful bits transmitted per second.
- Packet delay for both voice and video traffic – the interval between the instant that a packet arrives and the instant that packet is sent out successfully.
- Packet dropping rate for both voice and video traffic – the fraction of discarded packets due to the delay bound violation.

### 4.2.1 Simulation Results

We carry out simulations to compare the proposed algorithm with a greedy resource allocation scheme. In the greedy resource allocation scheme, each node selects a number of subcarriers to meet its current traffic demand. The subcarrier selection is considered to be random. Transmit power is uniformly distributed over the selected subcarriers.

If a subcarrier is chosen by more than one node, we assume that a collision occurs, and that subcarrier is wasted and does not contribute to the actual packet transmission rate. Packet scheduling with resource reservation is not taken into account in this greedy algorithm.

We evaluate the system performance in terms of the throughput, packet delay, and packet dropping rate. We let \( N_c = 100 \) and \( L_c = 4 \), and study the impact of the number of links on the system performance for both algorithms. For the sake of a fair comparison, we employ the same call admission control for both the proposed algorithm and the greedy scheme. Here, serving as a benchmark, we set the maximum number of admitted voice calls and that of admitted video calls to be 13 and 12, respectively. Fig. 2 shows the system throughput performance in serving three traffic types versus the number of links. The curve of system capacity defined by the maximum achievable system throughput is also plotted for reference. Clearly, our optimality-driven resource allocation algorithm achieves a higher system throughput and hence higher resource utilization than the greedy one. In fact, regarding the proposed algorithm, there are two key factors determining the trend of the curve, namely traffic load and resource reservation for the real-time traffic. Since the network is not saturated, the higher the traffic load, the higher the throughput. The curve goes up from \( M_c = 5 \) to 20 as there are more traffic including both real-time and bursty data traffic. From \( M_c = 20 \) to 35, the effect of the resource reservation for QoS provisioning outweighs that of the increased traffic load, flattening the system throughput and pulling down utilization. From \( M_c = 35 \) onwards, the effect of the increased traffic load becomes more substantial, causing the curve to rise a bit. Concerning the greedy algorithm, the system throughput performance first improves from \( M_c = 5 \) to 25 due to an increased traffic load, but drops afterwards due to more packet collisions with the number of links. Notice that the system capacity increases with the number of links because of the multi-user diversity. It is noteworthy that there is an obvious performance gap between the system throughput obtained from our algorithm and the system capacity, ascribed to the low traffic load and resource reservation for QoS provisioning. We observe that the system throughput and the resource utilization for the proposed algorithm can be ameliorated when the traffic load increases. In Fig. 3, the voice/video packet dropping rates are depicted. The packet dropping rates for both voice and video traffic are capped (by the level of 1%) in the proposed algorithm, whereas in the greedy approach, the packet dropping rates for both voice and video traffic increase from \( M_c = 5 \) to 15 and then roughly level off afterwards (due to the call admission control). It is observed

<table>
<thead>
<tr>
<th>Traffic Type</th>
<th>Traffic Model Parameter</th>
<th>Value</th>
<th>QoS Requirements Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voice</td>
<td>Mean ON Period</td>
<td>1.00s</td>
<td>Constant Data Rate</td>
<td>32Kbps</td>
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<tr>
<td></td>
<td>Mean OFF Period</td>
<td>1.35s</td>
<td>Delay Bound</td>
<td>70ms</td>
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<tr>
<td></td>
<td>Packet Inter-arrival time</td>
<td>20ms</td>
<td>Packet Loss Rate</td>
<td>1%</td>
</tr>
<tr>
<td>Video</td>
<td>Mean ON Period</td>
<td>1.47s</td>
<td>Minimum Data Rate</td>
<td>256Kbps</td>
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<tr>
<td></td>
<td>Mean OFF Period</td>
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<td>Delay Bound</td>
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<tr>
<td></td>
<td>Packet (Frame) Inter-arrival time</td>
<td>5ms</td>
<td>Packet (Frame) Loss Rate</td>
<td>1%</td>
</tr>
</tbody>
</table>
that the greedy scheme has poor packet dropping performance and basically cannot provide the same level of QoS assurance offered by our optimality-driven algorithm. Concerning the packet delay performance for both voice and video traffic, we observe that the packet delays of voice and video traffic in our proposed algorithm are about 8ms and 9.5ms, respectively, almost independent of the link number. Both the packet delays in the greedy approach are around 2.5ms. Apparently, the greedy scheme seems to have better delay performance for the real-time traffic. The fact, however, is that the successful packet transmission rate in the greedy scheme is so low that the dispersion of the delay experienced by those packets is small. On the contrary, the proposed algorithm achieves good performance compromise among the throughput, packet dropping rate, and packet delay. Our simulation results reinforce the idea that greedy (or random) resource allocation cannot efficiently provision QoS, leading to poor resource utilization and system performance. To acquire higher resource efficiency, the methodology of the optimality-driven resource allocation algorithm is demonstrated promising, thereby facilitating QoS provisioning and improving system resource utilization.

5. CONCLUSION

Effective and efficient resource allocation is essential for melliorating system performance in WMNs with heterogeneous traffic. In this paper, we have proposed a low-complexity algorithm for the joint power-frequency-time intra-cluster resource allocation problem. In the numerical analysis, our proposed algorithm is shown to be close to optimal. Simulation results demonstrate that our resource allocation algorithm performs better than the greedy approach, utilizing the network resources more efficiently and providing a better performance tradeoff among the throughput, packet delay, and packet dropping rate. Robust node clustering and novel inter-cluster scheduling tailored for WMNs are related important issues, which need further investigation.

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7. REFERENCES