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Joint Power and Rate Control for QoS Guarantees in Infrastructure-based Multi-hop Wireless Network using Goal Programming

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ABSTRACT

Quality of Service (QoS) Guarantees grant ways for service providers to establish service differentiation among subscribers. On the other hand, service subscribers are also assured the level of service they paid for. In addition, the efficient level of service quality can be selected according to the subscribers' needs thus ensuring efficient use of available bandwidth. While network utility optimization techniques assure certain QoS metrics, a number of situations exist where some QoS goals are not met. The optimality of the network parameters is not mandatory to guarantee specified QoS levels. This paper proposes a joint data rate and power control scheme that guarantees service contract QoS level to a subscriber using Goal Programming. In using goal programming, this paper focuses on finding the range of feasible solutions as opposed to solving for the optimal. In addition, in case no feasible solution is found, an acceptable compromised solution is solved.

Key words: Quality of Service, Goal Programming, Power Control, Rate Control, Wireless Network

1. INTRODUCTION

The service provider and subscriber views on network service performance are two opposing standpoints in establishing wireless access network architecture. On the service provider's side, the minimization of network set-up cost is a significant factor in network planning. On the other hand, subscribers are more concerned with obtaining the best performance for what they paid for. However, increasing the performance of a system incurs shelling out additional capital on new equipment. The provision of quality of service (QoS) guarantees introduces a compromise between service providers and subscribers. QoS guarantees provide efficient service differentiation among subscribers while assuring these subscribers the level of service they need. Also, the efficient level of service quality for subscriber's application is provided. For example, a delay-tolerant subscriber applicant can be given a lower service quality in terms of delay since delay would not produce a significant degradation in the application. In doing this, other subscribers whose applications require real-time delivery can be provided sufficient resources. QoS metrics may translate to throughput, delay, jitter, power or other parameters as defined by the service providers.

QoS implementation is usually incorporated in routing and scheduling optimization [1-7]. However, the goal of routing and scheduling opti-

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mization approaches is to maximize the overall network utility, in other words finding the global solution. Achieving this goal may only marginally meet the QoS requirements. A slight change in network parameters can lead to not meeting one or two QoS metrics. In addition, finding the global solution that meets all the QoS guarantees is an NP-hard problem. For a QoS network, global optimization approaches may generally not be suitable.

In line with this problem, this paper proposes the use of goal programming approach in solving the optimization of system resource to maintain QoS levels. The idea of goal programming [8-9] is to establish a goal level of achievement for each criterion. This approach is ideal in cases where meeting range or threshold values are more important than achieving the global optimum. In addition, this approach is effective when the optimum point that satisfies all goals is not feasible.

For this reason we propose a data rate and power control scheme that guarantees service contract QoS level. To optimize the data rate and power, goal programming approach is used with threshold goals given by the QoS metrics.

The contributions of this paper are as follows:

- propose a joint data rate and power control scheme to guarantee service level Quality of Service.
- propose a solution methodology that would provide the best solution possible even if the optimal solution is infeasible.

2. RELATED WORKS

Since the deployment of Internet, QoS has been one of the well-researched areas to improve Internet performance. The Internet Engineering Task Force (IETF) [10] has been working on effective QoS definitions and implementations. Since the conception of QoS, a number of methods have already been proposed to implement service differentiation and service guarantees [1-7]. Optimization [1-4] has always been one of the methods used. By using optimization, network parameters are optimized to meet QoS goals. A number of methodologies are used such as statistical methods [1] and algorithm/iterative optimization [2-4]. Most of these techniques aim to achieve a global solution. However, global optimization of goals may be insufficient for long-term guarantees. In addition, it is possible that not all goals are met at when optimum parameters are used. In most cases, infeasible solutions can occur. In such cases, global optimization may fail in that it cannot find the solution. This paper applies an optimization technique that minimize the variation from a specified range of values. The best possible solution is solved in case there is no feasible optimal solution.

In addition to optimization methods, rule-based methodologies can also be used to assure QoS [5-7]. This is achieved by using QoS policies that aid in resource allocation. However, similar to optimization methods, it is difficult to attain QoS goals when a number of contrasting policies are considered. Moreover, the adaptability and flexibility of rules are issues needed to be addressed.. Eventually the policies considered would be obsolete and need to be updated for changing traffic behavior. Thus, it would be more difficult to arrive at the best performance.

We consider a joint power and rate control similar to proposals in [10] and [11]. In our case, we consider the use of goal programming to add to the flexibility of the solutions. In addition, if there are no optimal solutions, the best possible solution would be used.

3. QUALITY OF SERVICE AND CONTROL PARAMETERS

Quality of Service can be viewed as a measure of subscriber satisfaction. When the Internet was first deployed, provision of QoS was not implemented. The default QoS that was used at that time was termed as "best effort service." With the implementation of QoS, service differentiation among subscribers gave the service providers ways to efficiently management system resources while satisfying their customers.

Service providers define the QoS metrics offered to subscribers. From these metrics, the subscriber purchases a range of values to be guaranteed by the service providers. For instance, the service providers could offer levels of guarantees for delay Table 1.

The subscriber can avail of the appropriate service quality level that can satisfy their application. Each service quality level is associated with a cost that the service providers evaluated. The best service quality level is associated with the highest compensation. For this paper, three QoS metrics are considered: 1) Throughput, 2) Delay and 3) Signal Quality. These metrics are influenced by the data rate used and power.

3.1 Throughput Metric

For multi-hop networks, packet forwarding is a significant factor that influences the network throughput. The location of subscribers, in relation to other subscribers, affects the data rate used for transmission.

Figure 1 illustrates the multi-hop scenario. In this scenario, two subscriber nodes S and T are connected to router M through subscriber node R. Uplink traffic from subscriber nodes S and T are sent to subscriber node R which forwards the packets to router M .Suppose all subscriber nodes

Table 1. Example of Delay QoS metric

Delay Quality of Service Metric		
Level	Delay	Cost
1	d = 10ms	A
2	10ms < d = 15ms	B
3	15ms < d = 20ms	C
4	d < 20ms	D

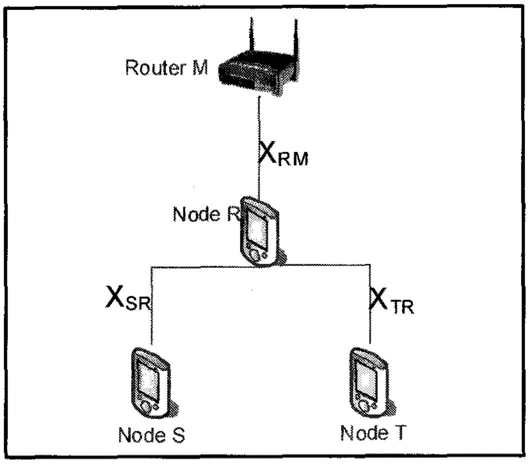

Fig. 1. Wireless Multi-hop Scenario

R, S and T have some traffic to send to router M. Also let X^i_{MAX} denote the maximum data rate that is available to a subscriber i. In this situation, subscriber node i would not be able to transmit using the maximum data rate due to the packets that needs to be forwarded from its neighbor nodes defined by set N_i. Some resources available to subscriber i would be used to serve other subscribers. Given the link data rate from a certain node i to a node j, x_{ij}, the law of flow conservation states that the data rate sent by subscriber node i is given by $\mu_i X^i_{MAX} = \sum_{j\in N_i} x_{ij} - \sum_{k\in N_i} x_{ki}$. The parameter μ_i denotes the fraction of the available data rate guarantee that is actually used by subscriber node i for its own purposes. In general, the fraction of the purchased guarantee used is given by Eq. (1).

$$\mu_i = \sum_{j\in N_i} \frac{x_{ij}}{X^i_{MAX}} - \sum_{k\in N_i} \frac{x_{ki}}{X^i_{MAX}} \tag{1}$$

where

- μ_i: fraction of the maximum available data rate used by subscriber i
- x_{ab}: link data rate from some source(a) to some destination(b)
- X^i_{MAX}: maximum available data rate for subscriber i
- N_i: set of neighbors of subscriber i

The parameter $\mu_i \in [0,1]$ relates to the throughput guarantee purchased by the user. In detail, the range of the data rate that a subscriber can use is represented by $\mu_{QoS} = [\mu_{\min}, 1]$.

3.2 Delay Metric

Gamez et. al. [12] studied different delay estimation algorithms. In their study, they concluded that the exponential averaging algorithm can give the best prediction for the delay in 802.11 wireless LAN networks. This result is used in this paper to predict the delay experienced in the network. The predicted delay is formulated as Eq. (2). The weighting factor used for the numerical example is 0.1 as it was proved by Gamez et.al. [12] to have the least error when compared with the actual delay for 802.11 multi-hop networks. This implies that delays from previous iterations are more significant, compared to the current data rate, in predicting the delay for the next iteration. However, note that continuous communication at a constant rate would yield to a linear increase in the delay. Also, the value of the weighting factor can be changed according to the type of network used. The proposed method in this paper adjusts the rate that would ensure that the delay experienced is within the delay limits the subscriber paid for. The QoS metric used is formulated as $D_{QoS} = [D_{\min}, D_{\max}]$.

$$D = \alpha x_{ij} + (1-\alpha) D^{-} \tag{2}$$

where

- D: predicted delay
- D^{-}: delay from previous iteration
- x_{ij}: data rate of link*(i,j)*
- α: weighting factor

3.3 Signal Quality

In order to quantify the signal quality of the links, the researcher makes use of the Signal to Interference Noise Ratio (SINR). The SINR value incorporates the transmission medium quality as well as interference caused by neighborhood transmission. The transmission medium quality represents how noisy the medium is. This is an important consideration given that unlicensed frequency bands are used in most wireless networks. This means that other standards such as Zigbee, WiMAX, UWB, WLAN etc are sharing the medium. In the numerical example, the 802.11 standard is used for the wireless network. The transmissions by other standards are seen by 802.11 nodes as noise. In addition, natural noise provided by environmental conditions is also considered when talking about transmission medium quality. Figure 2 illustrates the interference caused by neighbor transmissions. In this situation subscriber node R is communicating with router M with transmission power at P_R. Within router M's neighborhood, subscriber node B is also communicating with a subscriber node A with transmission power at P_B. In general the SINR is given as Eq. (3). It should be noted that in actual implementation, the exact value of the power received can not be obtained. In the case of 802.11, the received signal strength indicator (RSSI) may be used. RSSI is an estimate of the transmitted power

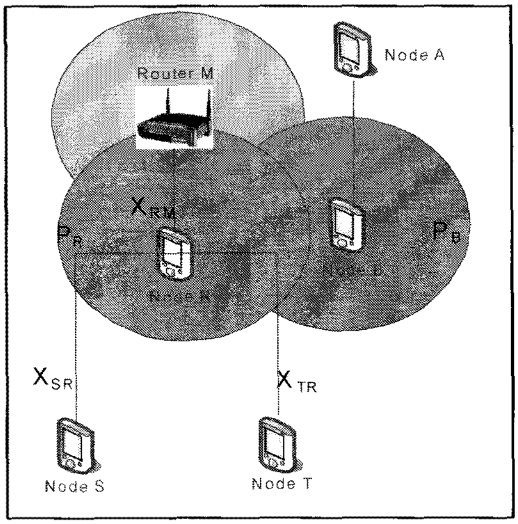

Fig. 2. Interference caused by Neighbor Transmission

received by the receiver. The QoS metric for Signal Quality can be represented by .

$$SINR_i = \frac{P_i}{P_{j,j\neq i} + Noise_{mean}} \quad (3)$$

where

- P_i: power received by some node i
- $Noise_{mean}$: average noise experienced

4. GOAL PROGRAMMING FORMULATION

To optimize the system parameters used, the goal programming approach is considered. In goal programming, the objective is to find the closest point to the optimal point in which the set of goals are met. This approach is especially useful in the case where the optimal point is not feasible. If the optimal solution is feasible, a range of solutions that satisfy the QoS guarantees can also be calculated.

4.1 Constraints

The constraints for the goal programming problem are given by Eq. (4). The optimal point is calculated such that it satisfies both the QoS guarantees and these constraints. The first constraint gives the upper bound for the link data rates in each link. The upper bound is defined by the Shannon-Hartley equation given by $C\log(1+SINR)$ for a given SINR value. The second constraint states that the link data rates can not be a negative value. The third constraint gives the lower and upper bounds for the power. Finally, the last constraint limits the value of μ_i to be within [0,1].

$$\begin{aligned} &x_{ij} \le Clog(1+SINR_i) \quad \forall (i,j) \\ &x_{ij} \ge 0 \\ &0 \le P_i \le P_{MAX} \qquad \forall i \\ &\mu_i \in [0,1] \end{aligned} \quad (4)$$

4.2 Goal Programming Problem

The goal programming problem is given by Eq. (5). The proposes scheme in this paper controls the data rate and power to achieve the range of QoS metrics which is purchased by the user. The range of the QoS guarantees is shown in brackets. Goal Programming can be solved using two models. The first model is Archimedian Approach. This model uses penalty weight for over-estimation and under-estimation of goals. The second model is the pre-emptive model. This model generates solutions in a lexicographic sense. In other words, this model arrives at solutions using priorities. In this paper, the preemptive model is used. The Archimedian model can also be used to solve the problem to consider weighing of objectives. The preemptive model is used in this paper to minimize the complexity in computations. Also, in wireless networks, prioritization is easier implemented as compared to finding weights. The prioritization can also be included as part of the QoS specifications purchased by the subscribers.

$$\begin{aligned} &goal\left\{\mu_i = \sum_{j\in N_i}\frac{x_{ij}}{X^i_{MAX}} - \sum_{k\in N_i}\frac{x_{ki}}{X^i_{MAX}}\right\} \quad [\mu_{\min}, 1] \\ &goal\{D = \alpha x_{ij} + (1-\alpha)D^-\} \quad [D_{\min}, D_{\max}] \\ &goal\left\{SINR = \frac{P_i}{P_{j,j\neq i} + Noise_{mean}}\right\} \quad [SINR_{\min}, SINR_{\max}] \\ &such\,that, \\ &x_{ij} \le Clog(1+SINR) \quad \forall (i,j) \\ &x_{ij} \ge 0 \\ &0 \le P_i \le P_{MAX} \qquad \forall i \\ &\mu_i \in [0,1] \end{aligned} \quad (5)$$

4.3 Preemptive Goal Programming

In preemptive goal programming, the solution is computed by assigning priorities for each goal and solving them sequentially. The problem is first expanded to the form given in Eq (6). The QoS guarantees are incorporated in the formulation as part of the constraints. In addition, dummy variables d^+ and d^- are introduced to represent over-estimation and under-estimation of the goals, respectively. The objective is to minimize the over-estimation and under-estimation variables such that the QoS guarantees are met.

Note that the notation *lex min* describes the priority of the constraints. Moreover, in cases where there is no feasible solution, the best solution is found by minimizing the deviations from the specified QoS range in Eq. (5). These deviations are represented by the dummy variables d^+ and d^-. To solve the preemptive programming problem, the problem is decomposed according to priority described by Eq. (6). Eqs. (7)-(9) details the decomposition of the problem in Eq. (6). In this paper we prioritize Signal Quality since it has effects on the assignment of data rates.

$$\begin{aligned}
& lex\min\left\{(d_i^{+1}, d_i^{-1}), (d_i^{+2}, d_i^{-2}), (d_i^{+3}, d_i^{-3})\right\} \\
& such\,that, \\
& \sum_{j\in N_i}\frac{x_{ij}}{X^i_{MAX}} - \sum_{k\in N_i}\frac{x_{ki}}{X^i_{MAX}} - d_i^{+2} \le 1 \\
& \sum_{j\in N_i}\frac{x_{ij}}{X^i_{MAX}} - \sum_{k\in N_i}\frac{x_{ki}}{X^i_{MAX}} + d_i^{-2} \ge \mu_{\min} \\
& \alpha x_{ij} + (1-\alpha)D^- - d_i^{+3} \le D_{\max} \\
& \alpha x_{ij} + (1-\alpha)D^- + d_i^{-3} \ge D_{\min} \\
& \frac{P_i}{P_{j,j\neq i} + Noise_{mean}} - d_i^{+1} \le SINR_{\max} \\
& \frac{P_i}{P_{j,j\neq i} + Noise_{mean}} + d_i^{-1} \ge SINR_{\min} \\
& x_{ij} \le C\log(1+SINR) \qquad \forall (i,j) \\
& x_{ij} \ge 0 \\
& 0 \le P_i \le P_{MAX} \qquad \forall i \\
& \mu_i \in [0,1] \\
& d \ge 0 \qquad \forall d
\end{aligned} \tag{6}$$

$$\begin{aligned}
& \min\left\{d_i^{+1} + d_i^{-1}\right\} \\
& such\,that, \\
& \frac{P_i}{P_{j,j\neq i} + Noise_{mean}} - d_i^{+1} \le SINR_{\max} \\
& \frac{P_i}{P_{j,j\neq i} + Noise_{mean}} + d_i^{-1} \ge SINR_{\min} \\
& 0 \le P_i \le P_{MAX} \qquad \forall i \\
& d \ge 0 \qquad \forall d
\end{aligned} \tag{7}$$

$$\begin{aligned}
& \min\left\{d_i^{+2} + d_i^{-2}\right\} \\
& such\,that, \\
& \sum_{j\in N_i}\frac{x_{ij}}{X^i_{MAX}} - \sum_{k\in N_i}\frac{x_{ki}}{X^i_{MAX}} - d_i^{+2} \le 1 \\
& \sum_{j\in N_i}\frac{x_{ij}}{X^i_{MAX}} - \sum_{k\in N_i}\frac{x_{ki}}{X^i_{MAX}} + d_i^{-2} \ge \mu_{\min} \\
& x_{ij} \le C\log(1+SINR) \qquad \forall (i,j) \\
& x_{ij} \ge 0 \\
& d \ge 0 \qquad \forall d
\end{aligned} \tag{8}$$

$$\begin{aligned}
& \min\left\{d_i^{+3} + d_i^{-3}\right\} \\
& such\,that, \\
& \alpha x_{ij} + (1-\alpha)D^- - d_i^{+3} \le D_{\max} \\
& \alpha x_{ij} + (1-\alpha)D^- + d_i^{-3} \ge D_{\min} \\
& x_{ij} \le C\log(1+SINR) \qquad \forall (i,j) \\
& x_{ij} \ge 0 d \ge 0 \qquad \forall d
\end{aligned} \tag{9}$$

5. NUMERICAL ANALYSIS AND RESULTS

The scenario depicted in Figure 2 is used for numerical analysis. In this scenario our goal is to find the appropriate values for x_{RM}, x_{SR}, x_{TR} and P_R that will meet the QoS guarantee provided. The numerical parameters are given in Table 2.

Solving the first priority goal in Eq. (7), we arrive

Table 2. Simulation Parameters

Simulation Parameters	
P_B	10 mW
$SINR^I_{max}$	2
$SINR^I_{min}$	1
$SINR^B_{max}$	1
$SINR^B_{min}$	0.7
X^I_{MAX}	0.5Mbps
X^J_{MAX}	0.3Mbps
X^K_{MAX}	0.3Mbps
D^I_{max}	5ms
D^J_{max}	5ms
D^K_{max}	5ms
D^-	5ms
C	1Mbps
α	0.1

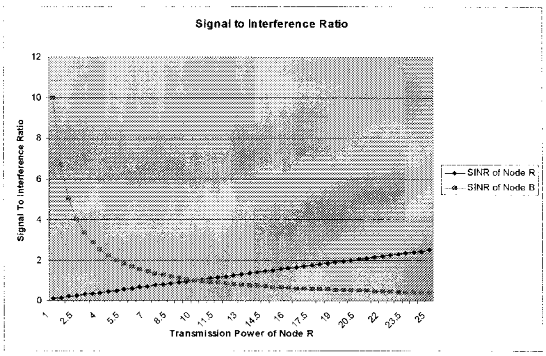

Fig. 3. Signal to Interference Noise Plot

Table 3. Signal Quality Optimization

P®	SINR®	dR1+	dR1-	SUM(dR1+, dR1-	SINR(T)	dT1+	dT1-	SUM(dR1+, dR1-	Total SUM
0.5	0.05	0	1.05	1.05	20	19	0	19	20.05
1	0.1	0	1	1	10	9	0	9	10
1.5	0.15	0	0.95	0.95	6.666667	5.666667	0	5.666666667	6.616667
2	0.2	0	0.9	0.9	5	4	0	4	4.9
2.5	0.25	0	0.85	0.85	4	3	0	3	3.85
3	0.3	0	0.8	0.8	3.333333	2.333333	0	2.333333333	3.133333
3.5	0.35	0	0.75	0.75	2.857143	1.857143	0	1.857142857	2.607143
4	0.4	0	0.7	0.7	2.5	1.5	0	1.5	2.2
4.5	0.45	0	0.65	0.65	2.222222	1.222222	0	1.222222222	1.872222
5	0.5	0	0.6	0.6	2	1	0	1	1.6
5.5	0.55	0	0.55	0.55	1.818182	0.818182	0	0.818181818	1.368182
6	0.6	0	0.5	0.5	1.666667	0.666667	0	0.666666667	1.166667
6.5	0.65	0	0.45	0.45	1.538462	0.538462	0	0.538461538	0.988462
7	0.7	0	0.4	0.4	1.428571	0.428571	0	0.428571429	0.828571
7.5	0.75	0	0.35	0.35	1.333333	0.333333	0	0.333333333	0.683333
8	0.8	0	0.3	0.3	1.25	0.25	0	0.25	0.55
8.5	0.85	0	0.25	0.25	1.176471	0.176471	0	0.176470588	0.426471
9	0.9	0	0.2	0.2	1.111111	0.111111	0	0.111111111	0.311111
9.5	0.95	0	0.15	0.15	1.052632	0.052632	0	0.052631579	0.202632
10	1	0	0.1	0.1	1	0	0	0	0.1
10.5	1.05	0	0.05	0.05	0.952381	0	0	0	0.05
11	1.1	0	0	0	0.909091	0	0	0	0
11.5	1.15	0	0	0	0.869565	0	0	0	0
12	1.2	0	0	0	0.833333	0	0	0	0
12.5	1.25	0	0	0	0.8	0	0	0	0
13	1.3	0	0	0	0.769231	0	0	0	0
13.5	1.35	0	0	0	0.740741	0	0	0	0
14	1.4	0	0	0	0.714286	0	0	0	0
14.5	1.45	0	0	0	0.689655	0	0.010345	0.010344828	0.010345
15	1.5	0	0	0	0.666667	0	0.033333	0.033333333	0.033333
15.5	1.55	0	0	0	0.645161	0	0.054839	0.05483871	0.054839
16	1.6	0	0	0	0.625	0	0.075	0.075	0.075
16.5	1.65	0	0	0	0.606061	0	0.093939	0.093939394	0.093939
17	1.7	0	0	0	0.588235	0	0.111765	0.111764706	0.111765
17.5	1.75	0	0	0	0.571429	0	0.128571	0.128571429	0.128571
18	1.8	0	0	0	0.555556	0	0.144444	0.144444444	0.144444
18.5	1.85	0	0	0	0.540541	0	0.159459	0.159459459	0.159459
19	1.9	0	0	0	0.526316	0	0.173684	0.173684211	0.173684
19.5	1.95	0	0	0	0.512821	0	0.187179	0.187179487	0.187179
20	2	0	0	0	0.5	0	0.2	0.2	0.2
20.5	2.05	0.05	0	0.05	0.487805	0	0.212195	0.212195122	0.262195
21	2.1	0.1	0	0.1	0.47619	0	0.22381	0.223809524	0.32381
21.5	2.15	0.15	0	0.15	0.465116	0	0.234884	0.234883721	0.384884
22	2.2	0.2	0	0.2	0.454545	0	0.245455	0.245454545	0.445455
22.5	2.25	0.25	0	0.25	0.444444	0	0.255556	0.255555556	0.505556
23	2.3	0.3	0	0.3	0.434783	0	0.265217	0.265217391	0.565217
23.5	2.35	0.35	0	0.35	0.425532	0	0.274468	0.274468085	0.624468
24	2.4	0.4	0	0.4	0.416667	0	0.283333	0.283333333	0.683333
24.5	2.45	0.45	0	0.45	0.408163	0	0.291837	0.291836735	0.741837
25	2.5	0.5	0	0.5	0.4	0	0.3	0.3	0.8

at the solutions for the subscriber node R transmission power as given by Figure 3 and Table 3. Figure 3 shows the plot of the SINR for subscriber nodes R and *B*. The SINR of subscriber *B* also varies with respect to the transmission power of subscriber node R since transmission of subscriber node R would be interpreted as noise by subscriber node *A*. From Figure 3, it can be observed that the optimum value of the power is when the $P_R = 11mW$. This is confirmed in Table 3. In addition, Table 3 also shows the range of transmission power values that would guarantee the QoS in terms of Signal Quality for subscriber nodes R and *B*. This range is shown as the shaded region in Table 3.

The values for the bit rate can be solved from Eq. (8) using the feasible transmission power values

Table 4. Upper Bound of xRM

P_R	$SINR_R$	Upper Bound of x_{RM}
11	1.1	0.46
11.5	1.15	0.47
12	1.2	0.49
12.5	1.25	0.508
13	1.3	0.52
13.5	1.35	0.535
14	1.4	0.54

calculated from Eq. (7). Substituting each of the feasible transmission power values to the Shannon-Hartley constraint, we get the values in Table 4. Table 5 shows the data rate assignments that would satisfy the QoS guarantee for throughput.

Table 5 provides the final solution to the data rate and power control scheme for the scenario in Figure 2. In this table, we consider the data rate configuration in combination with the transmission power assignment. Note that for power transmission at 11mW, 11.5mW and 12mw, only configuration A of the data rate can be used. This is because of the Upper Bound in the data rate for these transmission power assignments. This solution guarantees the QoS levels purchased by each subscriber. Note also multiple solutions are allowed which enables the service provider to adjust network parameters as needed.

Table 6 provides the final solution to the data rate and power control scheme for the scenario in Figure 2 In this table, we consider the data rate configuration in combination with the transmission power assignment. Note that for power transmission at 11mW, 11.5mW and 12mw, only configuration A of the data rate can be used. This

Table 5. Data Rate Assignments

Config ID	xSR	xTR	xRM	μR	μS	μT	SUM(d)	dR	dS	dT
A	0.1	0.1	0.4	0.4	0.333333	0.333333	0	4.5	4.533333	4.533333
B	0.1	0.1	0.5	0.6	0.333333	0.333333	0	4.5	4.533333	4.533333
C	0.1	0.2	0.5	0.4	0.333333	0.666667	0	4.5	4.533333	4.566667
D	0.2	0.1	0.5	0.4	0.666667	0.333333	0	4.5	4.566667	4.533333

Table 6. Data Rate and Power Control Assignment

P_R	Data Rate Configuration
11	A
11.5	A
12	A
12.5	A,B,C,D
13	A,B,C,D
13.5	A,B,C,D
14	A,B,C,D

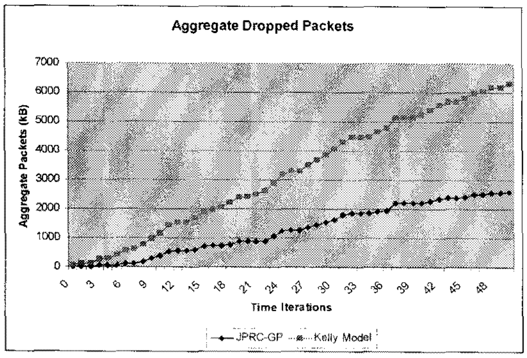

Fig. 4. Aggregate Dropped Packets

is because of the Upper Bound in the data rate for these transmission power assignments. This solution guarantees the QoS levels purchased by each subscriber. Note also that multiple solutions are allowed which enables the service provider to adjust network parameters as needed. We compared the amount of packet drops in using Kelly's Model [11] and the proposed scheme, denoted by JPRC_GP. In this scenario, each node R, *S* and Tare subjected to large amounts of packet arrival. In each node, the arrival of packets is set to 500Mb per time iteration. Figure 4 shows the amount of packets dropped. Similar to power consumption, the flexibility in choosing the data rates contributed to the gain achieved in performance.

6. CONCLUSION

Quality of Service (QoS) provides an area of compromise between service providers and subscribers. On the service provider's part, service differentiation is added which can help in efficient network planning to reduce implementation cost. On the other hand, subscribers are provided service guarantees for the service that they paid for. This paper proposed a joint data rate and power control assignment scheme to guarantee service contract QoS. Also, a goal programming approach was used to establish a goal level of achievement for each of the criteria analyzed Based on the results, a set of feasible assignment configuration was calculated that met the known QoS requirements as agreed upon by the service provider and the customers. Multiple solutions was found that allowed the service providers to adjust network parameters as needed. It was also shown that, in using the proposed scheme, the amount of traffic dropped due to congestion was less as compared to traditional Kelly Model networks.

REFERENCES

[1] L. Liu and G. Feng, "Research on Multi-constrained QoS Routing Scheme Using Mean Field Annealing," *Proceeding of the Sixth International Conference on Parallel and Distributed Computing, Applications and Technologies*, pp. 181-185, Dec. 2005.

[2] S. Roy et. al., "High-Throughput Multicast Routing Metrics in Wireless Mesh Networks," *Proceedings of the 26th International Conference on Distributed Computing Systems*, p. 48, 2006.

[3] Y. Li, et.al., "Distributed Adaptive Power Allocation for Wireless Relay Networks," *IEEE Transactions on Wireless Communications*, Vol.6, Issue 3, pp. 948-958, Mar. 2007.

[4] Pan Z., et.al., "Energy-Efficient Joint Power and Rate Control via Pricing in Wireless Data Networks," *Proceedings of the IEEE Wireless Communications and Networking*

Conference, pp. 1091-1096, Mar.-Apr. 2008.

[5] A. Raniwala and C. Tzi-cker, "Architecture and algorithms for an IEEE 802.11-based multi-channel wireless mesh network," *Proceedings of the 24th Annual Joint Conference of the IEEE Computer and Communications Societies, INFOCOM*, Vol. 3, pp. 2223-2234, Mar. 2005.

[6] V. Bejerano et. al., "Algorithms for computing QoS paths with restoration," *Proceedings of the 22nd Annual Joint Conference of the IEEE Computer and Communication Societies, INFOCOM 2003*, Vol.2, pp. 1435-1445, Mar.-Apr. 2003.

[7] Y. Ito and S. Tasaka, "Feasibility of QoS Control Based on QoS Mapping in Audio¿Video Transmission over IEEE 802.11 Wireless LANs," *Proceedings of the IEEE International Conference on Communications*, Vol.11, pp. 5097-5102, June 2006.

[8] R.E. Steuer, "Multiple Criteria Optimization: Theory, Computation, and Application," *Wiley Series in Probability and Mathematical Statistics*, 1986.

[9] J.P. Ignizio, "Goal Programming and extensions," *Lexington Books*, 1976.

[10] IETF, www.ietf.org.

[11] P. Kelly, A. Maulloo, and D. Tan, "Rate Control in Communication Networks: Shadow Prices, Proportional Fairness and Stability," *Journal of the Operational Research Society*, Vol.49, pp. 237-252, 1998.

[12] Gamez et.al., "Wireless Network Delay Estimation for Time-Sensitive Applications," *Research report ESAII RR-06-12*, http://paginespersonals.upcnet.es/~pmc16/nde_06.pdf, July 2006.

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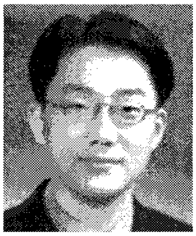

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