Paper

Quasi-Offline Fair Scheduling in Third Generation Wireless Data Networks

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Abstract—In 3G wireless data networks, network operators would like to balance system throughput while serving users fairly. This is achieved through the use of fair scheduling. However, this approach provides non-Pareto optimal bandwidth allocation when considering a network as a whole. In this paper an optimal offline algorithm that is based on the decomposition result for a double stochastic matrix by Birkhoff and von Neumann is proposed. A utility max-min fairness is suggested for the derivation of a double stochastic matrix. Using a numerical experiment, new approach improves the fairness objective and is close to the optimal solution.

Keywords—Birkhoff-von Neumann, max-min fairness, statistical optimization, wireless scheduling.

1. Introduction

Next generation wireless communication is based on a system of wireless mobile services that are transportable across different network backbones. Third generation networks such as the CDMA [1], and the Universal Mobile Telecommunications System (UMTS) [2] standardised by the European Telecommunications Standards Institute (ETSI) promise heterogeneous services to users that may be moved across various regions and networks. Recent 3G releases, often denoted 3.5G and 3.75G, also provide mobile broadband access of several Mbit/s to smartphones and mobile modems in laptops.

The 3G standard, called the 3G1X Evolution or High Data Rate (HDR) was designed for bursty packet data applications. It provides a peak downlink data rate of 2 Mbps and an average downlink data rate of 600 kbit/s within one 1.25 MHz CDMA carrier. HDR is commercially available, and HDR downlinks have a much higher peak data rate (2.4 Mbit/s) than others. Users share the HDR downlink using time multiplying with time slots of 1.67 ms each. Data frames can be transmitted to a specified user at any moment in time, and the data rate is determined by the user's channel condition. Users monitor pilot bursts in the downlink channel to estimate channel conditions in terms of Signal to Noise Ratio (SNR). Then, the SNR is mapped into a supported data rate. The data rate request channel information is transmitted using feedback to the base station. The duration of transmission to each user is determined by the downlink scheduling algorithm.

Several wireless scheduling have been proposed. The scheduling algorithm to satisfy the so-called proportional fairness was proposed by Jalali *et al*. [3]. The scheduling algorithm given by Borst *et al*. [4] provides dynamic control for fair allocation of HDRs. The 3G standard uses a scheduling algorithm [5]. Unfortunately, these algorithms give relative fairness to users rather than guarantee the required QoS performance.

Currently, some scheduling techniques to be used at the Medium Access Control (MAC) layer for high data rate Wireless Personal Area Networks (WPANs) were presented by Fantacci and Tarchi [6]. An efficient heuristic scheduling algorithm for MPEG-4 traffic in high data rate WPANs has been presented by Yang *et al.* [7]. However, these solutions have problems, such as computational complexity and rate granularity limitation.

The main objective of this paper is to introduce a new wireless scheduling algorithm that provides predetermined user throughputs. In addition, the paper will show that proposed scheduling algorithm is quasi-offline. It allows to remove the complexity of on-line scheduling. The main idea of presented scheduling the connection patterns is the Birkhoff decomposition [8] and von Neumann methodology [9].

In this paper, a statistical approach for Birkhoff-von Neumann methodology is used in which traffic demands are captured as statistical traffic distribution. For the derivation of a double stochastic matrix is proposed a utility max-min fair algorithm. In opposition to the von Neumann algorithm [9], the cumulative distribution functions that correspond to the given statistical profile is presented.

The remainder of the paper is organized as follows: In Section 2, a Birkhoff-von Neumann decomposition is presented which offers a quasi-offline scheduling strategy. Section 3 provides proposed wireless scheduling algorithm. In Section 4, some numerical experiments which were performed to examine the properties of the proposed algorithm are described. Some concluding remarks are given in Section 5.

2. Preliminaries

2.1. Birkhoff-von Neumann Decomposition

To explain the idea of Birkhoff-von Neumann decomposition, let $\overline{r} = (r_{i,j})$ be the rate matrix with $r_{i,j}$ being the rate allocated to the traffic from input i to output j for $N \times N$

permutation matrix. The traffic is admissible if and only if the following inequalities are satisfied, namely

$$\sum_{i=1} r_{i,j} \leq 1, \quad j = 1,2,\ldots,N \tag{1}$$

and

$$\sum_{j=1}^{N} r_{i,j} \leq 1, \quad i = 1,2,\ldots,N\,. \tag{2}$$

There exists a set of positive number ϕ_k and permutation matrix P_k, $k = 1,2,\ldots,K$ for some $K \leq N^2 - 2N + 2$ that satisfies

$$\bar{r} \leq \sum_{k=1}^{K} \phi_k p_k \tag{3}$$

and

$$\sum_{k=1}^{K} \phi_k = 1\,. \tag{4}$$

Generally, the Birkhoff-von Neumann methodology is performed offline. Unfortunately, the computational complexity of the decomposition is $O(N^{4.5})$.

Several method have been used to decreasing of the computational complexity. Among others, the Weighted Fair Queueing (WFQ) scheme as on-line algorithm has been proposed by Demers *et al.* [10]. Thus, the complexity of the on-line scheduling algorithm is $O(log\ N)$ as one needs to sort the $O(N^2)$ virtual finishing times in the WFQ-like algorithm.

2.2. Max-min Fairness

Maximizing aggregate utility is able to approach max-min fairness, if the utility function has a particular form. Max-min fairness an important requirement for wireless networks, such as multi-hop WANETs, MANETs, etc. [11]. To explain the idea of max-min fairness, let x be a vector, $x \in R^n$. Given a non-empty set $S \subseteq R^n$, a fairness concept supplies a way of designating some vector as the "best" one in S. A vector $x \in S$ is max-min fair if one cannot increase one of its components without decreasing another of its components that is already smaller or equal, while remaining in S.

In the following, an algorithm to obtain a utility max-min fairness is presented. In contrast to approaches in which the utility is defined with respect to service quality parameters [12], [13], this utility max-min fair algorithm is used to the Birkhoff-von Neumann decomposition problem under statistical traffic distribution.

In the proposed algorithm it was assumed that each row and column as being fixed or free. Initially, all rows and columns are free. Let ρ_i be the available capacity on row i and η_j be the available capacity on column j. Both values are initially equal to 1. The algorithm is repeated in the loop and at each iteration of the algorithm are consider only free columns and rows. Algorithm 1 shows the pseudocode of the proposed algorithm to obtain a utility max-min fairness.

Algorithm 1: A utility max-min fairness

Input: Flow rates specified as $N \times N$ matrix
while *exists free column or row* **do**
  for *each free flow i,j on row i temporarily* **do**
    allocate k_{ij} such that
    $\sum_{j\in T} k_{ij} = \rho_i,\ u_{ij}(k_{ij}) = \theta \quad \forall j \in T$
    where T is set of all columns
  end
  for *each free flow i,j on column j temporarily* **do**
    allocate k_{ij} such that
    $\sum_{j\in S} k_{ij} = \eta_j,\ u_{ij}(k_{ij}) = \theta \quad \forall i \in S$
    where S is set of all rows
  end
  find the minimum maximum common utiliy u_{ij} that could be achieved
  if *this minimum θ corresponds to row i*
  then *remove row i from S* **and** *fix the rate allocations:*
    $S = S - \{i\},\ \lambda_{ij} = k_{ij}$;
  end if;
  find the minimum maximum common utiliy u_{ij} that could be achieved
  if *this minimum θ corresponds to column j*
  then *remove column j from T* **and** *fix the rate*
    allocations: $T = T - \{j\},\ \lambda_{ij} = k_{ij}$;
  end if;
end
update the corresponding row and column capacities that are affected by the fixing of the λ_{ij};

3. Statistical Approach for Birkhoff-von Neumann Decomposition

In this section, a statistical approach for Birkhoff-von Neumann decomposition is presented. In this approach traffic requirements are described as statistical traffic distributions rather a vector fixed average rates.

The flow rates is specified as $N \times N$ matrix of probability density functions:

$$F = (f_0(x)) \tag{5}$$

where $f_0(x)$ is the probability distribution of traffic requirements for flow (i,j) and x be the rate allocation.

That long-term average throughput for $n, n = 1,\ldots,N$, is given by

$$T_n = \frac{\mu_n}{N} + \frac{\sigma_n}{N} G_N \tag{6}$$

and

$$G_N = N \int_0^1 u^{N-1} Q^{-1}(1-u)\,du\,, \tag{7}$$

where μ_n is the mean, σ_n is the variance $n = 1,2,\ldots,N$, $Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^\infty e^{-t/2} dt$.

Note that the Cumulative Distribution Function (CDF) of a Gaussian random variable depends only on the mean and the variance, because the average traffic flow does not depend on other traffic flows distribution.

For each $f_{i,j}(x)$ corresponding to the probability distribution of traffic requirements for flow (i,j), the CDF function is defined that describes the probability distribution of a random variable X that represents the actual traffic requirement. Thus, the CDF function of X is given by

$$\phi_{i,j}(x) = Pr[X \leq x], \tag{8}$$

where $\phi_{i,j}$ is the probability that the rate allocation x is sufficient to cover the actual traffic requirement.

To maximize the probability $\phi_{i,j}$, the CDF functions as utility functions can be used and derive the final rate allocation matrix.

4. Numerical Example

The traffic distribution is modeled as a Gaussian distribution. Each probability density function $f_{i,j}(x)$ can be defined with a given mean $\mu_{i,j}$ and a standard deviation $\sigma_{i,j}$. Consider 3×3 rate matrix with the following means and standard deviations:

$$\begin{pmatrix} \mu_{1,1} & \mu_{1,2} \\ \mu_{2,1} & \mu_{2,2} \end{pmatrix} = \begin{pmatrix} 0.4 & 0.4 \\ 0.4 & 0.4 \end{pmatrix}$$
$$\begin{pmatrix} \sigma_{1,1} & \sigma_{1,2} \\ \sigma_{2,2} & \sigma_{2,2} \end{pmatrix} = \begin{pmatrix} 0.05 & 0.1 \\ 0.1 & 0.05 \end{pmatrix} . \tag{9}$$

The decomposition algorithm originally proposed by von Neumann [9] is used to a double stochastic rate matrix Λ with the average traffic requirement matrix $\{\mu_{i,j}\}$ as the starting point. The von Neumann algorithm aims to increase the rate to make all row and column sums equal to 1, namely

$$\Lambda = \begin{pmatrix} 0.6 & 0.1 \\ 0.1 & 0.6 \end{pmatrix}. \tag{10}$$

The actual traffic requirement would be

$$\begin{pmatrix} 99.45\% & 50\% \\ 50\% & 99.45\% \end{pmatrix}. \tag{11}$$

By using the utility max-min fair algorithm to construct the doubly stochastic rate matrix $\Lambda = (\lambda_{ij})$ with the given Gaussian distribution function as utility functions, the following matrix can be obtained

$$\Lambda = \begin{pmatrix} 0.5 & 0.2 \\ 0.2 & 0.5 \end{pmatrix}. \tag{12}$$

Obtained result is better than the 50% probability that would be achieved by the von Neumann algorithm, namely

$$\Lambda = \begin{pmatrix} 99.64\% & 99.64\% \\ 99.64\% & 99.64\% \end{pmatrix}. \tag{13}$$

Summing up, the expected traffic can be modeled by the probability distribution for flow rates of HDR system. The utility max-min fair allocation algorithm can be used to construct the double stochastic rate matrix $\Lambda = (\lambda_{ij})$ with the CDF functions as the utility function.

5. Conclusion

It has been provided an algorithm to packet scheduling in wireless networks and has been formulated the problem in which traffic demands are captured as statistical traffic distribution. A utility max-min fair algorithm was used for the derivation of a double-stochastic matrix. This quasi-offline scheduling is attractive as it also largely removes the complexity of online wireless packet scheduling. Finally, the numerical results demonstrate that proposed solution achieves the required system performance.

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