A Distributed MAC Scheme for Large Network of Wireless Routers

Bin Zhao, Yingbo Hua

Abstract—For army, the mobility of an entire communication network is desirable. A large mobile communication network inevitably involves a large network of wireless routers. The throughput of a large network of wireless routers critically depends on distributed medium access control (MAC). In this paper, we present a MAC scheme to be called opportunistic synchronous array method (O-SAM). The O-SAM is distributed, locally executable and exploits channel fading opportunistically. We illustrate the throughput of a large network of wireless routers based on the O-SAM in comparison to other variations.

I. INTRODUCTION

For army, the mobility of an entire communication network is desirable. A large mobile communication network inevitably involves a large network of wireless routers. Each wireless router can serve as a virtual base station for many conventional mobile clients. The wireless routers are less mobile than the mobile clients and hence can reduce the networking/routing overheads significantly [1].

The throughout of a large network of wireless routers is critically important. It is known that the maximum network throughput \( c \) in bits-hops/s/Hz/node is bounded by a constant as the number of nodes (routers) becomes large [1] and [2]. The throughput unit “bits-hops/s/Hz/node” means the number of bits times the number of hops travelled by the bits per second per Hertz from each source node. This throughput unit is fundamental since the corresponding value of \( c \) does not depend on the node density nor the number of hops between a source node and a destination node. This value is also known as the pre-constant of the transport capacity of a large network [2]. Yet, the value of \( c \) critically depends on the nature of antennas (e.g., directional or omnidirectional, single antenna or array of antennas), the properties of the wireless media, as well as the medium access control (MAC) schemes applied.

In this paper, we will study the impact of MAC on the value of \( c \). In [3], the throughput of a large network based on the well known MAC scheme called “ALOHA” was analyzed. In [1], a new MAC scheme called synchronous array method (SAM) was proposed and analyzed. The SAM was shown to yield a much higher throughput than the ALOHA for both omni-directional antennas and directional antennas. But the SAM shown in [1] does not exploit the dynamic nature of channel fading. We will call the original SAM a deterministic SAM (D-SAM).

The new scheme shown in this paper is a generalization of the D-SAM, where the small scale channel fading is opportunistically exploited. The new scheme is hence called opportunistic SAM (O-SAM). We will show that the throughput of the O-SAM is significantly higher than that of the D-SAM when the small scale channel fading is present.

II. THE NETWORK MODEL

Consider a large network of wireless routers. Time is slotted with equal duration. During each time slot, the entire network is partitioned into \( S \) disjoint subnets \( \{C_j\}^S_{j=0} \). Each subnet \( C_j \) contains \( n_j + 1 \) active nodes and possibly other idle nodes. Fig. 1 shows an example of a large network on a square grid. Although the network topology is not required by the O-SAM and the general form of its analysis, we will use the topology shown in Fig. 1 for numerical illustration of network throughput.

In each time slot, the O-SAM is applied locally in each subnet, where only one packet is scheduled to transmit between a center node \( Z^0_j \) and one of its \( n_j \) neighbors \( \{Z^1_j, 1 \leq i \leq n_j\} \). The details of the scheme will be shown in section III.

The channel between two arbitrary nodes is modelled as a single input and single output channel. The channel gain experiences a large scale path-loss and a small scale Rayleigh fading. The signal \( Y_i \) received by any node in the subnet \( C_i \) can be expressed as

\[
Y_i = \sum_{j=0}^{S-1} h_{i,j} X_j + N_i
\]

where \( X_i \) is the desired signal component in \( Y_i \), \( X_j \) for \( j \neq i \) are interferences from other subnets, and \( N_i \) is
efficiency with the (ideal) detection threshold is captured by the following algorithm:

of SINR and hence the network throughput

Different MAC schemes affect differently the distribution of nodes in each subnet, and $R$ at the transmitter.

known, the instantaneous SINR is generally not available treated as noise. Since the network interference is un-
cancellation is not assumed, and thus interference is

interference variance, respectively. Successive interference

where $h_{i,j}$ is a complex Gaussian random variable with zero mean and the variance $E[|h_{i,j}|^2] = d_{i,j}^{-\alpha}$. $\alpha$ is the path loss exponent, and $d_{i,j}$ is the distance between the transmitter and the receiver. The noise variance is $N_0$. Given (1), the instantaneous Signal to Interference and Noise Ratio (SINR) in $C_0$ can be found as

\[
SINR = \frac{\nu_0}{N_0 + \sum_{j \neq 0} \nu_j}
\]

where $\nu_0$ and $\nu_j$ denote the signal variance and the interference variance, respectively. Successive interference cancellation is not assumed, and thus interference is treated as noise. Since the network interference is unknown, the instantaneous SINR is generally not available at the transmitter.

Given the above topology of the network, the network throughput in bits-hops/s/Hz/node is

\[
c = \frac{\mathcal{R}}{n} \times Pr \{ SINR \geq \xi \}
\]

where $Pr$ denotes probability, $n$ is the average number of nodes in each subnet, and $\mathcal{R}$ is the packet spectral efficiency with the (ideal) detection threshold $\xi = 2^{\mathcal{R}} - 1$. Different MAC schemes affect differently the distribution of SINR and hence the network throughput $c$.

III. THE OPPORTUNISTIC SAM

In each time slot, the center node in a subnet is the receiver, and one of its $n_j$ neighbors is the transmitter. Let the transmitter be indexed by $k_j$. Then, the O-SAM is captured by the following algorithm:

\[
k_j = \begin{cases} 
m_j & \text{if } |h_{Z_j^m, Z_j^m}| \geq \theta_j \\
\{\phi\} & \text{otherwise} \end{cases}
\]

\[
m_j = \arg \max_m \left\{|h_{Z_j^m, Z_j^m}|, 1 \leq m \leq n_j\right\}
\]

where $\{\phi\}$ denotes an empty set, $h_{Z_j^m, Z_j^m}$ denotes the channel gain between the center node $Z_j^0$ and its neighbor $Z_j^m$.

\[
Z_j^m. \text{This scheme exploits a multiuser diversity when } n_j > 1 \text{ and an interference suppression when } \theta_j > 0. \text{ Naturally, the O-SAM has the following three specializations:}
\]

- Multiuser-SAM (M-SAM) where $n_j > 1$ and $\theta_j = 0$;
- Switching-SAM (S-SAM) where $n_j = 1$ and $\theta_j > 0$;
- Deterministic-SAM (D-SAM) where $n_j = 1$ and $\theta_j = 0$.

We have done an analysis of the throughput $c$ for each of the above schemes in [4]. A numerical illustration of the (optimized) throughput is given in Fig. 2. Here, we used the topology as shown in Fig. 1 except $p = 3$ and $q = 2$. We see that the O-SAM consistently outperforms the three other schemes. We also observe that the O-SAM and S-SAM are not very sensitive to the choice of the detection threshold $\xi$. A comparison between M-SAM and D-SAM implies that the multiuser diversity dominates the throughput gain. A comparison of O-SAM and M-SAM implies that the interference suppression improves the robustness against an ill choice of the detection threshold $\xi$ or equivalently the packet spectral efficiency $\mathcal{R}$.

REFERENCES