Distributed Medium Access for a Large Wireless Mesh Network with Multiple Antenna Elements on Each Node

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Abstract— **This paper proposes a distributed MAC scheme for a large network of wireless routers with multiple antennas and characterizes its throughput gain over its single antenna counterpart in large network communications.**

Keywords— **Mesh networks, MIMO, media access control, opportunistic scheduling.**

I. Introduction

A large network of wireless routers is able to provide communication services in a flexible and expedient fashion, thus is especially suitable for ad hoc applications such as military deployment, disaster relief, environment inspection, etc. The throughput of such network depends on the design of medium access control (MAC) schemes as well as the properties of antennas and the conditions of wireless channels. This paper builds upon an existing distributed MAC scheme, i.e. Opportunistic Synchronous Method (O-SAM) [1], and examines its throughput in a large network of wireless routers equipped with multiple antenna elements.

Multiple antenna elements (MAEs) have been recognized and widely used as an effective physical layer technique to increase the throughput of isolated point to point wireless link [2]. In particular, [2] shows that when physical channel is sufficiently scattered, link throughput increases linearly with the number of MAEs (given the same number of MAEs employed at transmitter receiver) at asymptotically high Signal to Noise Ratio (SNR). However when communicating in a large scale network, co-channel interference instead of additive white Gaussian noise (AWGN) becomes the dominant throughput limiting factor. How to wisely design the signalling and the MAC schemes so that the favorable throughput enhancement features of MAEs can be achieved in the network setting is yet to be thoroughly examined. In addition, under network co-channel interference, the throughput gain of using MAEs need to be re-evaluated because asymptotically high SNR is no longer a realistic assumption due to the presence of mutually interfering links in large scale network.

This paper proposes a distributed MAC scheme for a large network of wireless routers equipped with MAEs and demonstrates its throughput advantages over its single antenna counterpart in large network communications. In particular, hybrid norm-based antenna selection criterion applied in the existing O-SAM scheme to control network interference. This paper also analyze in close-form the throughput as well as the outage probability of the proposed MAC scheme under network co-channel interference which, to our knowledge, has not be explored in the existing literature.

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This work was supported in part by the National Science Foundation under Grant No. TF-0514736, the U. S. Army Research Laboratory under the CTA Program Cooperative Agreement DAAD19-01-2-0011, and the U. S. Army Research Office under the MURI Grant No. W911NF-04-1-0224. The U. S. Government is authorized to reproduce and distribute reprints for Government purposes notwithstanding any copyright notation thereon.

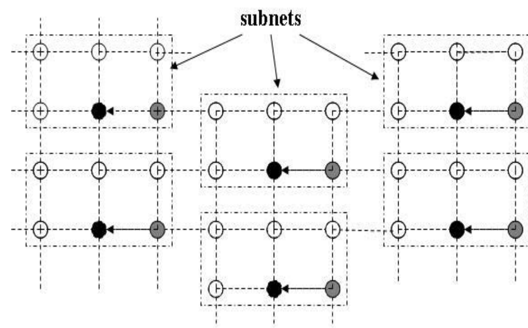

Fig. 1. A large network on a square grid. $(p, q, n) = (2, 3, 1)$.

The rest of the paper is organized as follows. Section II describes the network model and opportunistic SAM with MAEs. Section III present the throughput and outage analysis of the opportunistic SAM with MAEs. Section IV-C demonstrates the throughput gain of MAEs over single antenna with opportunistic SAM for a large network of wireless routers located on a square grid. The final conclusion is provided in section V.

II. Network Model

Consider a large network of wireless routers (referred to as nodes) where time is slotted with equal duration. During each time slot, the entire network is virtually partitioned into $S+1$ disjoint subnets $\{\mathcal{C}_j\}_{j=0}^{S}$. Each subnet $\mathcal{C}_j$ contains a center (receiving) node, n_j active neighboring (potentially transmitting) nodes, and m_j idle nodes. We assume that the network topology is fixed. Fig. 1 shows an example of such network distributed on a square grid where the black disks denote the center nodes, the gray disks the active neighbors, and the white disks the idle neighbors. For simplicity, adjacent nodes are separated by unit distance. In this example, each subnet is identical with $n_j = 3$ and $m_j = 2$. The center nodes are separated from each other with vertical spacing $p = 2$ and horizontal spacing $q = 3$. For different time slots, the pattern of the subnets is the same except for a relative relocation of the center nodes. With $p = 2$ and $q = 3$, it takes (at least) 6 time slots for each node on the network to become a center node. During each time slot, the MAC scheme, opportunistic SAM, is applied at each subnet, where only one packet is possibly scheduled for transmission from one of the active neighbors to their center node. The details of the opportunistic SAM will be given later in section III.

Each node is assumed to be equipped with M antenna elements. The channel between arbitrary transmitting antenna and receiving antenna is modeled as independently block fading with its coefficient assumed to experience a large scale path-loss and a small scale Rayleigh fading. The received signal $\mathbf{y}_0 \in \mathbb{C}^{\mathbb{M}}$ at the center node in the subnet $\mathcal{C}_0$ is an $M \times 1$ complex vector expressed as

$$\mathbf{y_0} \quad = \quad \sum_{j=0}^{S} \mathbf{H_{0,j}} \mathbf{x_j} + \mathbf{w_0} \tag{1}$$

Here $\mathbf{x_0} \in \mathbb{C}^{\mathbb{M}}$ is the signal-of-interest column vector transmitted from one of the active neighbors in $\mathcal{C}_0$, and $\mathbf{x_j}$ for $j \neq 0$ is transmitted from $\mathcal{C}_j$ for $j \neq 0$ which is the interference vector for $\mathbf{y_0}$. The complex noise vector $\mathbf{w_0}$ is assumed to be zero mean with covariance matrix $E\{\mathbf{w_0}\mathbf{w_0}^\dagger\} = \sigma^2 \mathbf{I_M}$, where I_M denotes $M \times M$ identity matrix. $\mathbf{H_{0,j}} \in \mathbb{C}^{\mathbb{M}\times\mathbb{M}}$ is the complex channel coefficient matrix between the transmitting node in $\mathcal{C}_j$ and the receiving node in $\mathcal{C}_0$. Each column $(\mathbf{H_{0,j}})_{:,\mathbf{i}}$ is a zero mean independent complex Gaussian vector, i.e. $E\{(\mathbf{H_{0,j}})_{:,\mathbf{i}}\} = \mathbf{0}$, $E\{(\mathbf{H_{0,j}})_{:,\mathbf{i}} (\mathbf{H_{0,j}})_{:,\mathbf{k}}^\dagger\} = \mathbf{0}, \forall \mathbf{i} \neq \mathbf{k}$, $E\{(\mathbf{H_{0,j}})_{:,\mathbf{i}} (\mathbf{H_{0,j}})_{:,\mathbf{i}}^\dagger\} = \mathbf{d_{0,j}^{-\alpha} I_M}$ where α is the path loss exponent and $d_{0,j}$ the distance between the transmitter in $\mathcal{C}_j$ and the receiver in $\mathcal{C}_0$. In the rest of the paper, we assume $\alpha = 4$. We further assume that all (transmitting) nodes transmit with the same power P, i.e. $E\{tr(Q_j)\} = P$, $Q_j = \mathbf{x_j}\mathbf{x_j}^\dagger$. We further assume that only local CSI (i.e. the channel matrix $\mathbf{H_{0,0}}$ between a center node and each of its neighbors) is available to the receiver and the local scheduler, but not the transmitter. However the scheduler will periodically broadcast a short message indicating which node and antenna is chosen to transmit during every time slot.

The throughput of a large network in bits-hops/s/Hz/node is

$$c = \frac{1}{n_j + m_j + 1} R_\xi P_d(\xi) \tag{2}$$

where R_ξ is the packet spectral efficiency in bits/s/Hz with the (ideal) detection SINR threshold $\xi = 2^{R_\xi} - 1$, and $P_d = Prob\{SINR \geq \xi\}$ is the packet delivery probability, and $n_j + m_j + 1$ is the number of nodes in each subnet. (For convenience of computing the throughput, we will assume that n_j and m_j are independent of j unless specified otherwise.)Different MAC schemes as well as physical layer signal processing techniques will affect differently the distribution SINR and hence the throughput c.

III. Opportunistic SAM with MAEs

[1] proposes opportunistic SAM to simultaneously exploit multiuser diversity and interference suppression for network communication with single antenna. In this section, we propose an MAE-based O-SAM scheme. In particular, we restrict our attention to a special signalling scheme of (1), where covariance matrix elements $(Q)_{k,j} = P\delta(k-i)\delta(j-i)$. This scheme allocates all power to a single transmitting antenna. A norm-based antenna selection method is used to decide which antenna,if any, will be chosen to transmit.

Since RF front-end is usually more costly than dummy antenna elements, we assume that each node only has $L \leq M$ independent RF receiving branches. In the presence of network co-channel interference, receiver uses match filtering along with hybrid selection/maximal-ratio combining (H-S/MRC) [3] to coherently combine the best L diversity branches in a pool of M antenna elements. H-S/MRC is a cost-effective physical layer technique to provide improved receiver performance over L branch MRC by raking additional diversity through antenna selection so that no additional electronics and power consumption is required. For notational simplicity, we define an operator $\Psi(\mathbf{h})$ that generates a $L \times 1$ submatrix of $\mathbf{h}$ such that among all the $L \times 1$ sub-matrix of $\mathbf{h}$ $\Psi(\mathbf{h})$ has the maximum norm. $\mathbf{I}_\Psi(\mathbf{h})$ denotes the row indices of $\Psi(\mathbf{h})$ in $\mathbf{h}$. $\mathbf{u}(\mathbf{I}_\Psi(\mathbf{h}))$ denotes a submatrix of $\mathbf{u}$ indexed by $\mathbf{I}_\Psi(\mathbf{h})$. It is straightforward that $\Psi(\mathbf{h}) = \mathbf{h}(\mathbf{I_\Psi}(\mathbf{h}))$.

For convenience, we consider subnet $\mathcal{C}_0$. Opportunistic SAM with MAEs can be captured by the following selection criterion. In particular, let the chosen transmitting antenna in $\mathcal{C}_0$ be denoted by a pair of index (k_0, i) where k_0 is the node index and i is the antenna index. Then, (k_0, i) is determined

$$(k_0, i) \quad = \quad \begin{cases} (k_{max}, i_{max}) & \text{if } \left|\Psi((\mathbf{H}_{0,0}(k_{max}))_{:,i_{max}})\right|^2 \geq \theta \\ \{\phi\} & \text{otherwise} \end{cases} \tag{3}$$

where $(k_{max}, i_{max}) = \arg\max_{k,i} \left\{ \left|\Psi((\mathbf{H}_{0,0}(k))_{:,i})\right|^2 \right\}$ in which $1 \leq k \leq n$ and $1 \leq i \leq M$. Here $\mathbf{H_{i,j}(k)}$ is used to denote channel coefficient between the center node in $\mathcal{C}_i$ and the k^{th} neighbor in $\mathcal{C}_j$ when opportunistic SAM involves more than one neighbor.

Given (3), the duty cycle p of each subnet can be found as

$$p = \int_\theta^\infty f_{\nu_{\max}}(x)dx \tag{4}$$

where $\nu_{\max} = \max_{k,i} \left\{ \left|\Psi((\mathbf{H}_{0,0}(k))_{:,i})\right|^2 \right\}$ for $1 \leq k \leq n$ and $1 \leq i \leq M$ denotes the probability density function (p.d.f.) of $\nu_{\max}$. Any abortion of transmission in a subnet reduces its interference to other subnets. Thus raising the threshold θ in each subnet reduces the total network co-channel interference. We will show in section IV-C that co-channel interference becomes less critical an issue when diversity order is sufficiently large in each subnet.

IV. Throughput Analysis

Given the MAC scheme, received signal (1) can be written

$$\mathbf{y_0} \quad = \quad h_{0,0}x_0 + \sum_{j=1}^{S} h_{0,j}x_j + w_0 \tag{5}$$

where $h_{0,j} = (\mathbf{H_{0,j}})_{:,\mathbf{l_i}}, \mathbf{l_i} \in \{\mathbf{1}, \ldots, \mathbf{M}\}$. Column index l_i is determined by the antenna selection algorithm (3) applied in each subnet.

With H-S/MRC, receiver chooses L diversity branches that have the best channel gain from a pool of M receive antennas. In particular, given $\mathbf{y_0}$, the best L diversity branches should be $\mathbf{y_0}(\mathbf{I_\Psi}(\mathbf{h_{0,0}}))$. After match filtering, the received signal becomes

$$\begin{aligned} r \quad &= \quad \Psi(\mathbf{h}_{0,0})^\dagger \mathbf{y}_0(\mathbf{I}_\Psi(\mathbf{h}_{0,0})) \\ &= \quad |\Psi(\mathbf{h}_{0,0})|^2 x_0 + \sum_{j=1}^{S} \Psi(\mathbf{h}_{0,0})^\dagger h_{0,j}(\mathbf{I}_\Psi(\mathbf{h}_{0,0}))x_j \\ &\quad\quad + \Psi(\mathbf{h}_{0,0})^\dagger w_0(\mathbf{I}_\Psi(\mathbf{h}_{0,0})) \end{aligned} \tag{6}$$

Since $E\{(\mathbf{H_{i,j}})_{:,\mathbf{k}} (\mathbf{H_{i,i}})_{:,\mathbf{l}}^\dagger\} = \mathbf{0}, \forall \mathbf{i} \neq \mathbf{j}, \mathbf{k} \neq \mathbf{l}$, antenna selection does not affect the statistical distribution of channel coefficient $\mathbf{h}_{0,j}, \forall 1 \leq i \leq S$, although they do affect the distribution of $\mathbf{h}_{0,0}$. By further examining each term in (6), we notice that given $\Psi(\mathbf{h}_{0,0})$ the scalar coefficient

$\Psi(\mathbf{h}_{0,0})^\dagger h_{0,j}(\mathbf{I}_\Psi(\mathbf{h}_{0,0}))$ is simply a linear combination of complex gaussian random variables (r.v.s) $h_{0,j}(\mathbf{I}_\Psi(\mathbf{h}_{0,0}))$, thus is still a complex gaussian r.v. with zero mean and variance $|\Psi(\mathbf{h}_{0,0})|^2 d_{0,j}^{-\alpha}$. As such, the interference power due to x_j is an exponential r.v. with mean $|\Psi(\mathbf{h}_{0,0})|^2 d_{0,j}^{-\alpha} E[|x_j|^2]$. Likewise, the noise term $\Psi(\mathbf{h}_{0,0})^\dagger w_0(\mathbf{I}_\Psi(\mathbf{h}_{0,0}))$ is also a complex gaussian r.v. with zero mean and variance $|\Psi(\mathbf{h}_{0,0})|^2\sigma^2$.

Since $E[x_i x_j^*] = 0, \forall i \neq j$ and $E[x_i x_i] = P$, the instantaneous signal to interference and noise ratio is

$$SINR = \frac{|\Psi(\mathbf{h}_{0,0})|^2}{\sum_{j=1}^{S} \nu_{0,j} + \sigma^2/P} \quad (7)$$

where $\nu_{0,j}$ is an exponential random variable with mean $d_{0,j}^{-\alpha}$. Comparing (7) with the SINR expression in [1], we notice that match filtering and antenna selection only change the distribution of signal power however the distribution of interference power remains the same. Therefore, the throughput of O-SAM with MAEs can be calculated using (2). In particular,

$$\begin{aligned} P_d(\xi) &= P_r\left\{\sum_{j\neq 0} \nu_{0,j} \leq \frac{|\Psi(\mathbf{h}_{0,0})|^2}{\xi} - \frac{\sigma^2}{P}, |\Psi(\mathbf{h}_{0,0})|^2 \geq \theta\right\} \\ &= \int_{\max\left\{\frac{\xi\sigma^2}{P},\theta\right\}}^{\infty} \int_0^{\frac{y}{\xi}-\frac{\sigma^2}{P}} f_{\nu_I}(x)dx f_{|\Psi(\mathbf{h}_{0,0})|^2}(y)dy \quad (8)\end{aligned}$$

where $\nu_I = \sum_j \nu_{0,j}$, $f_{\nu_I}(x)$ is the distribution of total network interference, and $f_{|\Psi(\mathbf{h}_{0,0})|^2}(x)$ is the distribution of signal power.

Following the same Laplace method in [1], $f_{\nu_I}(x)$ can be easily found as

$$f_{\nu_I}(x) = \mathcal{B}\delta(x) + \sum_{j=1}^{S}\sum_{l=1}^{n} \mathcal{A}_j^l \exp\{-x/\Gamma_{0,j}(l)\} \quad (9)$$

where $\Gamma_{i,j} = d_{i,j}^{-\alpha}$ and $\mathcal{B} = \prod_{j\neq 0} \overline{p_j}$

$$\mathcal{A}_j^l = \frac{p_j^l}{\Gamma_{0,j}(l)} \prod_{k\neq 0,j}\left(\overline{p_k} + \sum_{m=1}^{n_k} p_k^m \frac{1/\Gamma_{0,k}(m)}{1/\Gamma_{0,k}(m) - 1/\Gamma_{0,j}(l)}\right)$$

$$\begin{aligned}\overline{p_j} &= \prod_{l=1}^{n}\left(1 - e^{-\theta/\Gamma_{j,j}(l)}\right) \\ p_j^l &= \int_\theta^\infty \frac{1}{\Gamma_{j,j}(l)} e^{-x/\Gamma_{j,j}(l)} \prod_{k\neq l}\left(1 - e^{-x/\Gamma_{j,j}(k)}\right) dx\end{aligned}$$

Since $\int_0^\infty f_x(\nu)d x = 1$, it holds that $\mathcal{B} + \sum_{j=1}^{S}\sum_l \mathcal{A}_j^l \Gamma_{0,j}(l) = 1$. Also note that if $\theta = 0, \forall j \neq 0$, then $\mathcal{B} = 0$. For simplicity, we assume that from now on $\Gamma = \Gamma_{i,i}(k)$. Extension to arbitrary $\Gamma_{i,i}(k)$ is straightforward.

The distribution of scalar $|\Psi(\mathbf{h}_{0,0})|^2$ also depends on the transmit antenna selection scheme in (3). In particular, we consider two cases.

A. Random Selection with $n = 1$

Notice that random selection is different from the norm-based transmit antenna selection criterion used in (3). It is included mainly as a performance benchmark. In addition, the analytical results derived for random selection serves as a foundation for analyzing the norm-based antenna selection scheme.

To find the distribution of $|\Psi(\mathbf{h}_{0,0})|^2$, order statistics need to be applied to $\mathbf{h_{0,0}}$. In particular, $\mathbf{h_{0,0}}$ is a complex gaussian random vector with zero mean and covariance matrix I_M. Thus the channel gain of each diversity branch is i.i.d. r.v. with exponential distribution $f_{\gamma_i}(x_i) = \frac{1}{\Gamma} exp\{-x_i/\Gamma\}, \forall x_i \geq 0$. Assemble diversity branches so that $\gamma_{(i)} \geq \gamma_{(j)}, \forall i \leq j$

$$f_{\{\gamma_{(i)}\}_{i=1}^M}(x_1,\ldots,x_M) = M!\prod_{i=1}^{M} e^{-x_i/\Gamma}/\Gamma,\ x_1 \geq \cdots \geq x_M \quad (10)$$

H-S/MRC combines L branches with the maximum channel gain, thus $|\Psi(\mathbf{h}_{0,0})|^2 = \sum_{i=1}^{L} x_i$. Since the distribution of the ordered branches is no longer independent, finding the p.d.f. of $|\Psi(\mathbf{h}_{0,0})|^2$ involves M-layer nested integration of (10) over $\{x_i\}_{i=1}^M$. Such burden can be alleviated by decoupling $\{x_i\}_{i=1}^M$ through a linear transformation [3]:

$$\gamma_{(i)} = \sum_{n=i}^{M} \frac{\Gamma}{n} V_n \quad (11)$$

where $\{V_n\}_{n=1}^M$ are i.i.d. r.v.s with p.d.f.

$$f_{\{V_n\}_{n=1}^M}(v_1, v_2, \ldots, v_M) = \prod_{n=1}^{M} e^{-v_n}, 0 \leq v_n \leq \infty \quad (12)$$

Therefore,

$$|\Psi(\mathbf{h}_{0,0})|^2 = \sum_{i=1}^{L} x_i = \sum_{i=1}^{L} V_i + \sum_{i=L+1}^{M} \frac{L}{i} V_i \quad (13)$$

For convenience, we assume $\Gamma = 1$. For arbitrary Γ the following result still hold as long as both signal power and interference power are normalized by Γ. Using Laplace transform, the characteristic function of r.v. $|\Psi(\mathbf{h}_{0,0})|^2$ is

$$\mathcal{F}_{|\Psi(\mathbf{h}_{0,0})|^2}(\mathcal{U}) = \frac{1}{(\mathcal{U}+1)^L}\prod_{i=1}^{M-L}\frac{L+j}{L+j+L\mathcal{U}} \quad (14)$$

Using partial fractional decomposition and inverse Laplace transform, we find the p.d.f. for $|\Psi(\mathbf{h}_{0,0})|^2$,

$$f_{|\Psi(\mathbf{h}_{0,0})|^2}(y) = \sum_{i=1}^{L} \frac{a_i x^{i-1}}{(i-1)!} e^{-x} + \sum_{i=L+1}^{M} a_i e^{-\frac{i}{L}x} \quad (15)$$

where

$$a_j = \begin{cases} \sum_{k=1}^{M-L} \frac{(-1)^{L+k-j-1} L^{L-j} M!}{k^{L+1-j} L!(k-1)!(M-L-k)!} & 1 \leq j \leq L-1 \\ \frac{M!}{L!(M-L)!} & j = L \\ \frac{L^{L-1} M!(-1)^{j-1}}{(j-L)^L L!(j-L-1)!(M-j)!} & L+1 \leq j \leq M \end{cases} \quad (16)$$

Plugging (15)(9) into (8) and using identity

$$\int_0^y x^{i-1} e^{-ax} dx = \frac{(i-1)!}{a^i}\left(1 - e^{-ay}\sum_{k=0}^{i-1}\frac{(ay)^k}{k!}\right), a > 0 \quad (17)$$

the packet delivery ratio becomes,

$$
\begin{aligned}
P_d(\xi) &= \sum_{j=L+1}^{M} a_j e^{-\frac{j\tau}{L}} \frac{L}{j} + e^{-\tau} \sum_{i=1}^{L} \sum_{j=i}^{L} \frac{a_j \tau^{i-1}}{(i-1)!} \\
&\quad - \sum_{j=1}^{S} \mathcal{A}_j^1 e^{\sigma^2/(P\Gamma_{0,j})} \lambda(j) \qquad (18)
\end{aligned}
$$

where $\tau = \max\{\frac{\sigma^2 \xi}{P}, \theta\}$

$$
\begin{aligned}
\lambda(j) &= \sum_{i=L+1}^{M} \frac{a_i}{\frac{i}{L} + \frac{1}{\xi\Gamma_{0,j}}} e^{-\tau\left(\frac{1}{\xi\Gamma_{0,j}} + \frac{i}{L}\right)} \\
&\quad + e^{-\tau(1+\frac{1}{\xi\Gamma_{0,j}})} \sum_{i=1}^{L} \sum_{k=i}^{L} \frac{a_k \tau^{i-1}/(i-1)!}{(1+\frac{1}{\xi\Gamma_{0,j}})^{k-i+1}}
\end{aligned}
$$

B. Norm-based Selection with $n \geq 1$

Given (3),

$$
|\Psi(\mathbf{h}_{0,0})|^2 = \max_{1 \leq k \leq n, 1 \leq i \leq M} \left\{ \left| \Psi((\mathbf{H}_{0,0}(k))_{:,i}) \right|^2 \right\}
$$

Since the p.d.f. of r.v. $\left|\Psi((\mathbf{H}_{0,0}(k))_{:,i})\right|^2$ is given by (15), it is straightforward that the c.d.f. of r.v. $|\Psi(\mathbf{h}_{0,0})|^2$ is

$$
\begin{aligned}
F_\Psi(y) &= \prod_{i=1}^{nM} P_r\{\left|\Psi((\mathbf{H}_{0,0}(k))_{:,i})\right|^2 \leq y\} \\
&= \left(1 - \sum_{k=1}^{L} \sum_{j=0}^{k-1} \frac{a_k y^j e^{-y}}{j!} - \sum_{k=L+1}^{M} \frac{a_k e^{-yk/L}}{k/L}\right)^{nM} \qquad (19)
\end{aligned}
$$

where identity $\sum_{k=1}^{L} a_k + \sum_{k=L+1}^{M} \frac{a_k}{k/L} = 1$ is used in the last step. Plugging (19)(9) into (8),

$$
\begin{aligned}
P_d(\xi) &= 1 - F_\Psi(\tau)\left(1 - \sum_{j=1}^{S} \sum_{l=1}^{n} \mathcal{A}_j^l e^{\frac{\sigma^2}{P\Gamma_{0,j}(l)} - \frac{\tau}{\xi\Gamma_{0,j}(l)}}\right) \\
&\quad - \sum_{j=1}^{S} \sum_{l=1}^{n} \mathcal{A}_j^l \int_{\tau}^{\infty} e^{\frac{\sigma^2}{P\Gamma_{0,j}(l)} - \frac{x}{\xi\Gamma_{0,j}(l)}} \frac{F_\Psi(x)}{\xi\Gamma_{0,j}(l)} dx
\end{aligned}
$$

To compute the last term, tedious expansion of $F_\Psi(x)$ into multiple additive terms is necessary which is omitted here for brevity.

C. Numerical Results

To illustrate the throughput advantages of opportunistic SAM with MAEs over its single antenna counterpart, we consider a square grid in Fig. 1 with 50×50 nodes. We focus on the saturated network throughput achieved at high transmit power, i.e. $\frac{P}{\sigma^2} = 50dB$.

Fig. 2 shows the performance scaling of H-S/MRC with respect to the number of receiving RF links. We include the throughput of single antenna O-SAM as a benchmark. Given $n = 1$ and random antenna selection, Fig. 2 essentially shows the throughput of each mutually interfering SIMO links, thus the throughput gain mainly comes from receiver diversity. As $L \to M$ throughput quickly saturates at $M = L$. Further notice that interference suppression ($\theta = \theta_{opt}$) does not increase the peak throughput of O-SAM when diversity order is sufficient, i.e. $M >> 1$, although it does provide throughput robustness against spectral efficiency. Fig.3 demonstrates the performance scaling with both transmitter diversity and receiver diversity. When $n > 1$, the same feature of throughput scaling holds except that additional spatial diversity is gain due to the presence of multiple active neighbors. Comparing "$M = 8, L = 6$" curve in Fig.2 and "$M = L = 6$" curve in Fig.3, we observe that significant throughput gain is achievable through transmitter antenna selection.

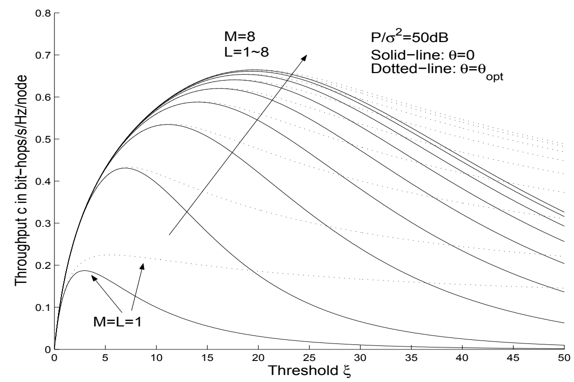

Fig. 2. The throughput comparison of O-SAM with MAEs vs. its single antenna counterpart. H-S/MRC is used at receiver while random antenna selection is used at transmitter.

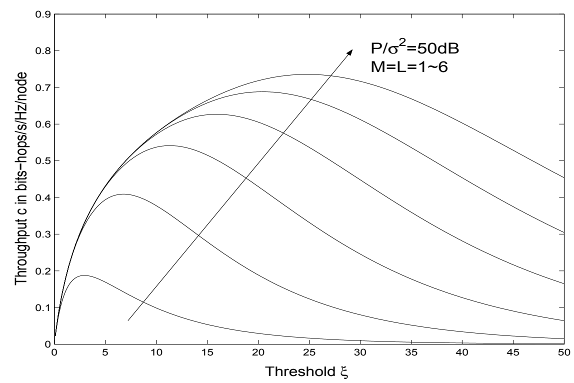

Fig. 3. Throughput scales with the number of antenna elements M. Threshold $\theta = 0$.

V. Conclusion

In this paper, we propose a distributed MAC scheme for multiple antennas communications in a large scale wireless mesh network. Analytical results demonstrate that even with naive diversity schemes significant throughput gain can be achieved. This motivates cross-layer design of multiple antenna signalling and MAC to optimize the throughput of mutually interfering links in a large scale network.

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