Multi-Rate Channel Design in Wireless Networks Exploiting Multi-Channel Beamforming Techniques

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Abstract— **The use of multi-beam antennas provides a wireless network node with the capability of concurrent communications with multiple nodes in different directions. Multi-beam antennas have been shown to improve network throughput as well as reliability. In this paper, we consider an array processing based framework in which channel collision is avoided for improved efficiency while interference to ongoing links is tolerable. In particular, new request of communication links is made through a lower-power packet with its data spreading over time. Such service requests can be transmitted any time when the target node is in a receive mode, irrespective to whether the target node is communicating with other nodes or not. Signal spreading ensures that the service request packets do not measurably interfere to the ongoing communication links yet it can be robustly decoded at the target node. The target node will determine the acceptance or denial of a service request based on the request signals.**

Keywords: Multi-channel beamforming, wireless network, array signal processing, multi-rate channel design

I. INTRODUCTION

Conventionally, wireless network nodes are equipped with omnidirectional antennas. Directional antenna techniques can enhance wireless network performance by improving spatial reuse and routing performance [1], [2]. With the use of directional antennas, a wireless network can provide longer transmission range and higher data rate, and strongly reduces signal interferences in unnecessary directions and jamming susceptibility.

Recently, the concept of directional antennas has been further extended to multi-beam antennas (MBAs) that enable a node to concurrent communications with multiple neighboring nodes (e.g., [3], [4], [5], [6], [7]). Multi-beam antennas can be implemented through multiple fixed-beam antennas (MFBAs) or multi-channel smart antennas (MCSAs). The former are convenient and cost-effective for fixed wireless networks where the beams of the directional antennas can be pre-optimized. They may experience significant performance degradation, however, for wireless networks consisting of mobile nodes since the locations (and directions) of the nodes are time-varying. In addition, wireless networks using MFBAs may experience significant throughput degradation in a rich multipath environment [8], [9].

MCSAs, on the other hand, are flexible in beam steering and thus support concurrent communications with multiple nodes with a substantially reduced probability of collision [5], [7]. In contrast to MFBAs, MCSAs can be designed to provide multi-fold advantages: (1) They can adaptively form nulls in the directions of interfering signals (co-channel interferers or jammers). (2) When a signal arrives with multiple paths, they achieve spatial diversity without exhausting additional degree-of-freedom. (3) They can tradeoff array gain, spatial multiplexing gain, and interference mitigation gain so as to obtain the optimum transmission performance [5], [7], [8], [9]. In addition, wireless networks using MCSAs provide lower probability of intercept (LPI) and support interference nulling to operate against hostile attacks.

In this paper, we consider an array processing based framework in which channel collision is avoided for improved efficiency and the maintenance of uninterrupted ongoing links. In other words, an ongoing link is entitled to continue the uninterrupted communications without repeatedly negotiating for channels. When another neighboring node intends to communicate with one of the nodes already in communication, the node issues a request-to-send (RTS) to the target node. To ensure that the channel request packet does not measurably interfere to the ongoing communication channels, the RTS packet is sent with a lower transmit power and its data is spread over a long time. Thus, such request can be sent during any time when the target node is in a receive mode, irrespective to whether the target node is communicating with other nodes.

When the RTS is received at the target node, it has to determine whether to accept the request for a new link. Such decision is made based on the judgement whether the ongoing as well as the new communication links can maintain sufficient output signal-to-interference-plus-noise ratio (SINR) for quality assurance. It is shown that it is feasible to assess the level of mutual interference between existing and new users and the decision can be made based on the predicted output SINR performance.

II. CHANNEL CONTENTION DESIGN

When the MCSAs are used in a wireless network, conventional carrier sense multiple access (CSMA) and carrier sense multiple access with collision avoidance (CSMA/CA) schemes are not well suited because an MCSA-based network can accept concurrent transmission of multiple data streams. Rather, the source node (SN) and target node (TN) have to assess the interference as whether a data transmission can be initiated and a request can be accepted. The effect of interference is bidirectional, i.e., the new SNs will generate interference to the ongoing links, and they will also receive interference from the ongoing links. In deciding the acceptance of the new SNs, all the ongoing and accepting links should be guaranteed to have sufficiently high SINR. Thus, a platform feasible for the SINR assessments is desirable.

Many wireless networks adopt a separate control channel for RTS/CTS exchange to negotiate one of the available free data channels. For the MCSAs, such approaches may have several problems. (1) Collision may occur in the control channel when more than one users request for data channel and none of them would success. In MCSAs, however, depending on the unused spatial degrees-of-freedom (DOFs), a TN may accept multiple new SNs. Therefore, allowing simultaneous requests from multiple SNs would be desirable. (2) The control channel is predesignated and it may not reflect the optimum bandwidth tradeoff between the control flow and data packets. This may result in significant resource waste, particularly

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when the data streams are of high load and new transmission requests are not very frequent.

In this paper, we propose the sharing of the control channel with the data channel by spreading the control signals into the data frame, i.e., transmitting a control signal bit using multiple bit intervals with a reduced power. As such, the control signals impose insignificant interference to the ongoing data packets, whereas the accumulation of signal power over multiple bit intervals allows sufficient energy for the control signal to be correctly received at the TN. The proposed scheme allows simultaneous transmission of the control signals from multiple SNs without collision, and the TN can decide to accept all, some, or none of the requested SNs. As a result, the system is more flexible and, by eliminating the control channel predesignation, the overall throughput may be improved.

In the following, we illustrate the processes of requesting new communication links and how the acceptance of such communication requests is determined.

III. REQUEST OF NEW COMMUNICATIONS LINKS

A. Design Concept

We demonstrate the proposed approach through a simple network topology illustrated in Fig. 1, where nodes A is a TN which is equipped with N antennas. Node A has established ongoing communication links with a set of nodes, denoted as S_o. The number of ongoing nodes is denoted as the cardinality of S_o, denoted as $K_o = |S_o|$. Node B is illustrated in Fig. 1 for example. Before other users join in, the array in node A is optimized to form beams for the communication with these nodes. Because of the multi-beam capability of node A, it can provide a standby channel so that new communication requests can be listened to avoid the deafness problem [5].

Now we consider a situation that node set S_n, illustrated as nodes S and T in Fig. 1, intend to originate new links to node A. Denote $K_n = |S_n|$ as the number of new requesting nodes. When these requesting nodes send their respective service request signals to node A, they may introduce interference to node A for the ongoing links with node set S_o. To maintain the ongoing link between node A and node set S_o from interruption due to the new service requests, the handshake requests from node set S_n should be transparent to the ongoing links, i.e., the interference from node set S_n should be low enough such that the existing links between nodes A and node set S_o are not significantly degraded, and nodes A as well as node set S_o need not to change their array weights during such handshaking process. Note that, this requirement should be satisfied regardless whether the service requests from node set S_n will be accepted by node A or not. In addition, there should be no significant mutual interference between the control signals transmitted from node set S_n. On the other hand, node A should receive enough signal energy from any node $s_j \in S_n$ if s_j, $j = 1, ..., K_n$, is admissible at node A, i.e., node A has an idle channel available for this node, and the interference from node s_j in a data transmission mode is acceptable.

Assume that the output SINR required for signal detection is ξ_0, and that required for the detection of service request signals is ξ_1. Then, the above discussion can be summarized as

$$\mathrm{SINR}_i \geq \xi_0, \ \text{for } s_i \in S_o, \tag{1}$$

and

$$\mathrm{SINR}_j \geq \xi_1, \ \text{for } s_j \in S_n, \tag{2}$$

where SINR_i and SINR_j are, respectively, the output SINR of ongoing users and new users, all conditioned that the ongoing signals and the service request signals are present.

In practice, the acceptable output SINR performance degradation is considered as an implementable measure. This is the margin the ongoing user(s) can tolerate. We discuss this measure in the following subsection.

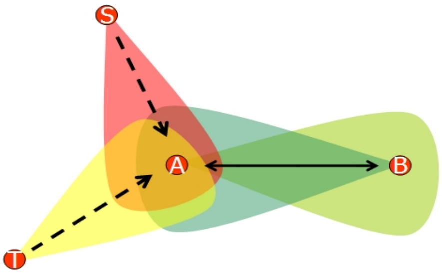

Fig. 1. Illustration of a wireless network exploiting the multi-channel beamforming technique.

B. Signal Model

In the following, we evaluate the effect of interference when new requesting nodes transmit their respective request packets at a lower rate and power. Before these requesting nodes join in, the signal received at node A from ongoing node set S_o is expressed in the following vector form,

$$\mathbf{x}(t) = \sum_{i=1}^{K_o} \sqrt{P_i} \mathbf{a}_i g_i(t) + \mathbf{n}(t), \tag{3}$$

where P_i denotes the received signal power, evaluated at node A, from node $s_i \in S_o$, $\mathbf{a}_i$ represents the corresponding spatial signature, which is assumed to have a norm of $||\mathbf{a}_i|| = \sqrt{N}$, where $|| \cdot ||$ denotes the vector norm, and $g_i(t)$ is the signal waveforms with a unit power. In addition, $\mathbf{n}(t)$ is the additive noise vector, whose elements are assumed to be independent to the signals and are modeled as complex Gaussian distributed with zero mean and variance σ_n^2. While the optimization of P_i may reduce the overall transmission power, we assume that P_i, $i = 1, ..., K_o$, takes an equal value of $P^{[o]}$ for simplicity. The specific determination of $P^{[o]}$ will be discussed later. Here we only assume that $P^{[o]}$ is a function of K_o, the umber of the active users.

In (3), we also make standard assumptions that the signals from different nodes are independent and identically distributed (i.i.d.). Then, the covariance matrix of the signal is evaluated as

$$\mathbf{R}_x^{[o]} = P^{[o]} \sum_{i=1}^{K_o} \mathbf{a}_i \mathbf{a}_i^H + \sigma_n^2 \mathbf{I} = P^{[o]} \mathbf{A}_o \mathbf{A}_o^H + \sigma_n^2 \mathbf{I}, \tag{4}$$

where $\mathbf{A}_o = [\mathbf{a}_1, ..., \mathbf{a}_{K_o}]$ and $\mathbf{I}$ is the $N \times N$ identity matrix. When the minimum mean square estimation (MMSE) criterion is used, node A uses the following optimal weight vector for the the ongoing link between nodes A and s_i,

$$\mathbf{w}_i = (\mathbf{R}_x^{[o]})^{-1} \mathbf{a}_i. \tag{5}$$

When new requesting node set S_n transmits service request signals, the signal received at node A becomes

$$\mathbf{x}(t) = \sqrt{P^{[o]}} \sum_{i=1}^{K_o} \mathbf{a}_i g_i(t) + \sqrt{P^{[n]}} \sum_{j=1}^{K_n} \mathbf{b}_j g_j(t) c_j(t) + \mathbf{n}(t), \tag{6}$$

where $P^{[n]}$ is the equal transmit power of the requesting nodes, and $\mathbf{b}_j$ is their respective spatial signatures which are also assumed to be of norm $|\mathbf{a}_j| = \sqrt{N}$. In addition, $c_j(t)$ is the binary spreading sequence corresponding to node s_j. Each code is of spreading gain of L and is assumed to be quasi-orthogonal with a cross-correlation coefficient of $1/L$ between each sequence pair.

When the service request signals are present, the weight vector towards the ongoing links are maintained the same as (5). For the standby channel, the following two weight vectors are considered:

$$\mathbf{w}^{[n]} = \mathbf{w}_0, \tag{7}$$

or

$$\mathbf{w}^{[n]} = (\mathbf{R}_x^{[o]})^{-1}\mathbf{w}_0, \tag{8}$$

where $\mathbf{w}_0 = [1, 0, \cdots, 0]^T$ is a vector corresponding to omnidirectional array pattern. Therefore, the weight vector depicted in (7) yields omnidirectional pattern, whereas (8) suppresses ongoing signals and otherwise shows no preference in other directions.

C. Output SINR Evaluation and Power Designation

First, we consider the output SINR of an ongoing link in the presence of only ongoing links. In this case, the output SINR of the link between node A and node $s_i \in S_o$ is well known and is given by

$$\mathrm{SINR}_i^{[o]} = \frac{P^{[o]}|\mathbf{w}_i^H\mathbf{a}_i|^2}{P^{[o]}\sum\limits_{\substack{k=1\\k\neq i}}^{K_o}|\mathbf{w}_i^H\mathbf{a}_k|^2 + \sigma_n^2||\mathbf{w}_i||^2} = P^{[o]}\mathbf{a}_i^H(\mathbf{R}_x^{[o-i]})^{-1}\mathbf{a}_i, \tag{9}$$

where

$$\mathbf{R}_x^{[o-i]} = P^{[o]}\sum_{\substack{k=1\\k\neq i}}^{K_o}\mathbf{a}_k\mathbf{a}_k^H + \sigma_n^2\mathbf{I}$$

is the covariance matrix of the interference and noise.

Next, we consider the output SINR of an ongoing link when service request signals are also present. The output SINR of the link between node A and node s_i, $s_i \in S_o$, is expressed as

$$\mathrm{SINR}_i^{[o+n]} = \frac{P^{[o]}|\mathbf{w}_i^H\mathbf{a}_i|^2}{P^{[o]}\sum\limits_{\substack{k=1\\k\neq i}}^{K_o}|\mathbf{w}_i^H\mathbf{a}_k|^2 + P^{[n]}\sum\limits_{j=1}^{K_n}|\mathbf{w}_i^H\mathbf{b}_j|^2 + \sigma_n^2||\mathbf{w}_i||^2}. \tag{10}$$

The SINR degradation factor due to service request signals is expressed as

$$\begin{aligned}\Delta\mathrm{SINR}_i &= \frac{\mathrm{SINR}_i^{[o+n]}}{\mathrm{SINR}_i^{[o]}}\\ &= 1 - \frac{P^{[n]}\sum\limits_{j=1}^{K_n}|\mathbf{w}_i^H\mathbf{b}_j|^2}{P^{[o]}\sum\limits_{\substack{k=1\\k\neq i}}^{K_o}|\mathbf{w}_i^H\mathbf{a}_k|^2 + P^{[n]}\sum\limits_{j=1}^{K_n}|\mathbf{w}_i^H\mathbf{b}_j|^2 + \sigma_n^2||\mathbf{w}_i||^2}.\end{aligned} \tag{11}$$

To determine an appropriate value of $P^{[n]}$, we consider the worst-case SINR degradation factor which happens when only one ongoing signal is present, and the service request signals occurs in the same direction of the ongoing signal. In this case,

$$\Delta\mathrm{SINR}_i = 1 - \frac{1}{1 + \dfrac{\sigma_n^2}{NK_nP^{[n]}}}. \tag{12}$$

To minimize the effect of service request signals to the ongoing links, a conservative solution is to make the contribution of the interference from service request signals much below the noise level, i.e., $NK_nP^{[n]} \ll \sigma_n^2$, or

$$P^{[n]} = \frac{\sigma_n^2}{\mu NK_n}, \tag{13}$$

where $\mu \gg 1$ is a constant representing the ratio between the noise power and the maximum possible power of all the service request signals. Substituting (13) into (12) yields the out SINR degradation factor in this case as

$$\Delta\mathrm{SINR}_i = \frac{\mu}{1+\mu}. \tag{14}$$

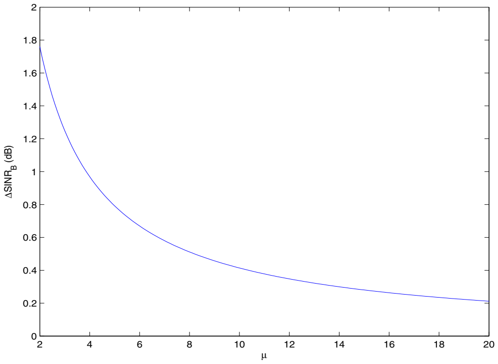

Fig. 2. Worst-case SINR_i loss (in dB) versus μ.

This result is illustrated in Fig. 2. When $\mu = 4$, the worst-case SINR loss is about 0.97 dB. The degradation factor becomes 0.41 dB when $\mu = 10$.

Now we evaluate the output SINR of the service request signals. After the received signal is despread corresponding to the spreading sequence used for node $s_j \in S_n$, the signal transmitted from node s_j is enhanced by the spreading gain L in the despreading process. When standby channel is omnidirectional, the signal received at node A, after despreading using the code matching user s_j, is expressed as

$$r_j(t) = \sqrt{LP^{[n]}}g_j(t) + \sqrt{P^{[o]}}\sum_{i=1}^{K_o}g_i(t) + \sqrt{P^{[n]}}\sum_{\substack{k=1\\k\neq j}}^{K_n}g_k(t) + n_j(t), \tag{15}$$

$$\mathrm{SINR}_j = \frac{LP^{[n]}}{K_oP^{[o]} + (K_n-1)P^{[n]} + \sigma_n^2} \approx \frac{LP^{[n]}}{K_oP^{[o]} + \sigma_n^2}. \tag{16}$$

The approximation is justified by the fact that $K_nP^{[n]} \ll \sigma_n^2$ as is clear from (13). Therefore, to satisfy the requirement as specified in (2), L should satisfy

$$L \geq \mu K_n\xi_1(K_o\xi_0 + N), \tag{17}$$

To reduce the required length of L, we can first remove the contribution of signals $s_i(t)$, $i = 1, ..., K_o$, from $r_j(t)$ before processing the service request signal because the ongoing signals can be decoded, with a highly reliability, due to the constraint set forth in (1). In this case, L should be chosen such that

$$L \geq \mu K_nN\xi_1. \tag{18}$$

Alternatively, weight vector (8) can be used for the suppression of ongoing signals when receiving the service request signals. In this case, the output SINR is expressed as

$$\begin{aligned}\mathrm{SINR}_j &= \frac{LP^{[n]}|[\mathbf{w}^{[n]}]^H\mathbf{b}_j|^2}{P^{[o]}\sum\limits_{i=1}^{K_o}|[\mathbf{w}^{[n]}]^H\mathbf{a}_i|^2 + P^{[n]}\sum\limits_{j=1}^{K_n}|[\mathbf{w}^{[n]}]^H\mathbf{b}_j|^2 + \sigma_n^2||\mathbf{w}^{[n]}||^2}\\ &\approx \frac{LP^{[n]}|[\mathbf{w}^{[n]}]^H\mathbf{b}_j|^2}{P^{[o]}\sum\limits_{i=1}^{K_o}|[\mathbf{w}^{[n]}]^H\mathbf{a}_i|^2 + \sigma_n^2||\mathbf{w}^{[n]}||^2}\\ &= \frac{LP^{[n]}|[\mathbf{w}^{[n]}]^H\mathbf{b}_j|^2}{\mathbf{w}_0^H[\mathbf{R}_x^o]^{-1}\mathbf{w}_0}.\end{aligned} \tag{19}$$

While the evaluation of the above expression is not necessarily straightforward for insightful observations, the denominator is upper bounded by the noise variance, whereas the numerator is approximately $LP^{[n]}$ when the service request signal is reasonably separated from the ongoing signals. Therefore, L specified in (18) remains a good approximation in this case as well, provided that the service request signals and the ongoing signals have moderately separated directions-of-arrival (DOA‘s).

IV. ACCEPTANCE/DENIAL OF SERVICE REQUESTS

A. Design Concept

Upon the receiving of the requests from s_j, $j = 1, ..., K_n$, TN node A should determine whether the request from these SNs can be accepted. The criteria becomes

$$\begin{aligned} &\max \sum_{j=1}^{K_n} \alpha_j \\ &\text{s.t.} \quad \mathrm{SINR}'_i \geq \xi_0, \qquad s_i \in S_o, \\ &\qquad\ \ \mathrm{SINR}'_j \geq \alpha_j \xi_0, \qquad s_j \in S_n, \end{aligned} \tag{20}$$

where α_j, $j = 1, ..., K_n$, equals to 1 if node s_j is accepted at node A, or 0 if node s_j is denied. In addition, SINR'_i and SINR'_j are, respectively, the output SINR of user signals i and j, when signal from user s_i is present for all $s_i \in S_o$, whereas for users $s_j \in S_n$, the presence of user s_j depends on the value of α_j. Node A needs to predict the output SINR for each of the users, and it is desired that it does so based solely on the information collected from the service request signals.

To compensate performance degradation due to co-channel interference, the target node A can request the ongoing and accepted nodes to slight raise their transmit power. While an optimization power control may be desirable for highest power efficiency, we adopt here a simple power increment by $\kappa(K_o + \sum_{j-1}^{K_n} \alpha_j - 1)$ dB in each ongoing and accepted nodes, where κ is a predetermined value. That is, each active node will transmit at power level $P' = \nu \cdot P_0$ where $\nu = 10^{[\kappa(K_o + \sum_{j-1}^{K_n} \alpha_j - 1)]/10}$ and P_0 is a constant representing the received signal power at node A when only a single source node is active.

B. SINR Prediction

Now we consider the prediction of SINR performance in case that some or all nodes $s_j \in S_n$ are accepted to transmit data packets with the normal data rate and the transmit power level P'. Depending on whether node s_j, $j = 1, ..., K_n$, are accepted to transmit their respective data streams, the covariance matrix becomes

$$\mathbf{R}_x = P' \sum_{i=1}^{K_o} \mathbf{a}_i \mathbf{a}_i^H + P' \sum_{j=1}^{K_n} \alpha_j \mathbf{a}_j \mathbf{a}_j^H + \sigma_n^2 \mathbf{I}. \tag{21}$$

If node s_j is accepted, then the MMSE weight vector at node A corresponding to node s_j is

$$\mathbf{w}'_j = \mathbf{R}_x^{-1} \mathbf{a}_j, \tag{22}$$

and the corresponding SINR is expressed as

$$\mathrm{SINR}'_j = P' \mathbf{a}_j^H \mathbf{R}_x^{-1} \mathbf{a}_j. \tag{23}$$

To evaluate the SINR corresponding to the signal transmitted from node $s_i \in S_o$, we have

$$\mathbf{w}'_i = \mathbf{R}_x^{-1} \mathbf{a}_i, \tag{24}$$

and the corresponding SINR is expressed as

$$\mathrm{SINR}'_i = P' \mathbf{a}_i^H \mathbf{R}_x^{-1} \mathbf{a}_i. \tag{25}$$

It is clear from the above discussion that the $\mathbf{R}_x$ in (21), together with $\mathbf{a}_i$ and $\mathbf{a}_j$, are required to predict SINR'_i and SINR'_j, $i = 1, ..., K_o$, $j = 1, ..., K_n$. To obtained these results in the service request phase, we notice that the corresponding covariance matrix of the received signal vector after proper despreading with the spreading code associated with user S, evaluated in the service request phase, is expressed as

$$\begin{aligned} \mathbf{R}_x^{[j]} &= P^{[o]} \sum_{i=1}^{K_o} \mathbf{a}_i \mathbf{a}_i^H + L P^{[n]} \mathbf{a}_j \mathbf{a}_j^H + P^{[n]} \sum_{\substack{k=1 \\ k \neq j}}^{K_n} \mathbf{a}_k \mathbf{a}_k^H + \sigma_n^2 \mathbf{I} \\ &\approx P^{[o]} \sum_{i=1}^{K_o} \mathbf{a}_i \mathbf{a}_i^H + L P^{[n]} \mathbf{a}_j \mathbf{a}_j^H + \sigma_n^2 \mathbf{I}, \end{aligned} \tag{26}$$

for a sufficiently large value of L. By subtracting the above covariance matrices by $\mathbf{R}_x^{[o]}$, depicted in (4), the information of $\mathbf{a}_j$ can be obtained. In addition, $\mathbf{R}_x$ can be estimated from

$$\mathbf{R}_x = \mathbf{R}_x^{[o]} + \sum_{j=1}^{K_n} \alpha_j (\nu M / L)(\mathbf{R}_x^{[j]} - \mathbf{R}_x^{[o]}), \tag{27}$$

where $M = P_0 / P^{[n]}$. As such, (4) and (26) provide all the necessary information to evaluate the MMSE weight vectors and output SINR corresponding to nodes s_i, $i = 1, ..., K_o$S, and s_j, $j = 1, ..., K_n$, and to determine whether all, part, or none of nodes s_j, $j = 1, ..., K_n$, should be accepted.

V. NUMERICAL RESULTS

We consider the topology setting as illustrated in Fig. 1, where an ongoing communication link between node A and B works well and node S and/or T can probably originate request packets to node A during the ongoing transmission. Assume that node A is equipped with an array consisting of five omnidirectional antennas. Four of them form a uniform circular array, whereas the other one is located at the center of the circle. The radius of the circle is about 0.35λ, yielding a $\lambda/2$ interelement spacing between the circular array elements, where λ is the wavelength. User B is located at $\phi = 0^{\circ}$, which is defined as the line linking the center element and one of the four circularly placed element.

Fig. 3 illustrates the actual output SINR performance degradation of user B when user S emits its service request signal. The results are depicted with respect to the DOA of user S, denoted as ϕ_S, where $\mu = 4$ is assumed. The maximum output SINR loss is 0.51 dB in this case, when node S and node B fall in the same DOA.

Fig. 4 illustrates the actual output SINR performance degradation of user B when two users, S and T, emit their service request signals. The results are depicted with respect to their respective DOAs, ϕ_S and ϕ_T. The same value of $\mu = 4$ is assumed. The maximum output SINR loss is 0.97 dB, which coincides with the results depicted in Fig. 2 and happens when both nodes S and T fall in the same DOA as node B.

To study the distribution of SINR degradation, we plot in Fig. 5 the distribution of $\Delta\mathrm{SINR}_{\mathrm{B}}$, assuming that the DOAs of the two service requesting nodes are uniformly distributed. However, when the DOAs of users S and T are assumed to follow a uniform angular distribution, the probability of having SINR loss of 0.5 dB and higher is less than 17% which occurs when at least one of the users is closely located with user B. The probability that the SINR loss is larger than 0.6 dB is only 5.5%.

In practice, there is a possibility that more than two service requesting signals may arrive at the same time. However, the probability that the SINR of user B significantly degrades is small. To demonstrate this, we plot in Fig. 6 the distribution of $\Delta\mathrm{SINR}_{\mathrm{B}}$, assuming three service requesting signals are present with a uniform distribution of their respective DOAs. The probability that the SINR degradation exceeds 1 dB is 1.2%. Note that the actual occurrence is further multiplied by the probability that three nodes transmit simultaneously.

In Fig. 7 the shaded area shows the range of ϕ_S and ϕ_T where the request from both nodes can be accepted such that all nodes will maintain an SINR level about the required level of ξ_0. The transmit power increment parameter is set to $\kappa = 2$ dB. Fundamentally, both users are accepted when they have sufficient angular separation from the ongoing node and to each other of themselves. The angular separation to accept the request from one user (S or T) is that the node is at least 33° from the ongoing node.

VI. CONCLUSIONS

We have considered the multi-rate channel design and implementation in wireless networks exploiting multi-channel beamforming techniques. It allows flexible service requests from multiple nodes without causing collision problems. The interference of service requesting signals to ongoing communication links is designed to be tolerable,

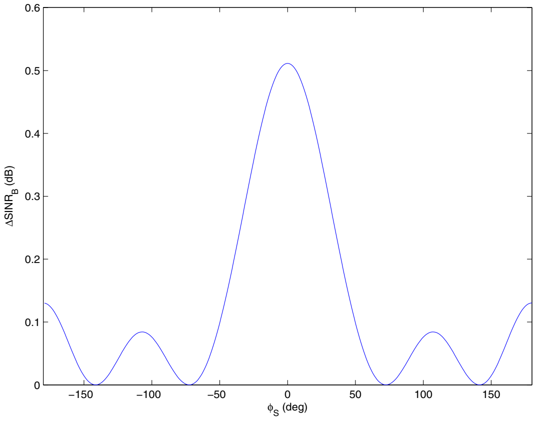

Fig. 3. Actual SINR_B loss (in dB) at the presence of a single service request node with respect to its DOA.

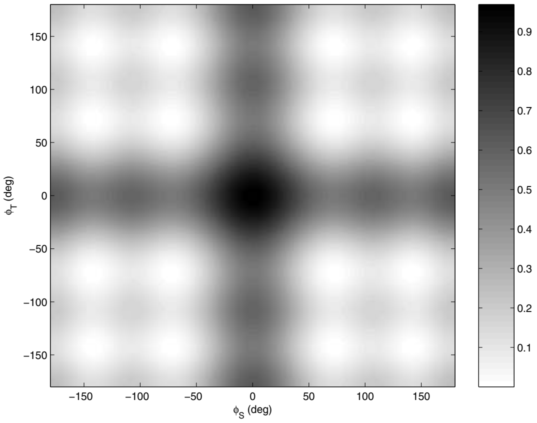

Fig. 4. Actual SINR_B loss (in dB) at the presence of two service requesting nodes with respect to the DOAs.

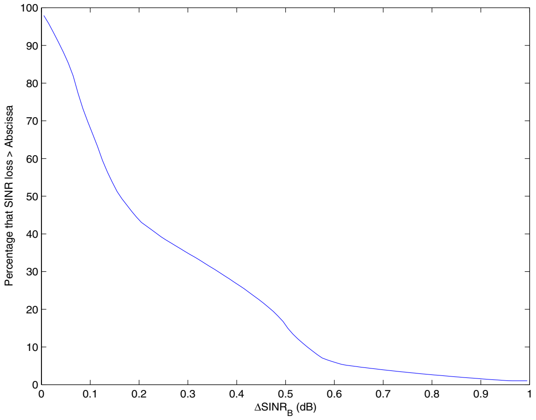

Fig. 5. Percentage of actual SINR_B loss (in dB) at the presence of two service requesting nodes.

and the acceptance of service requests is determined by the prediction of yielding output SINR ratio to maximize the network throughput without compromising the quality-of-service. The feasibility of the proposed method is validated through the output SINR performance analysis and prediction.

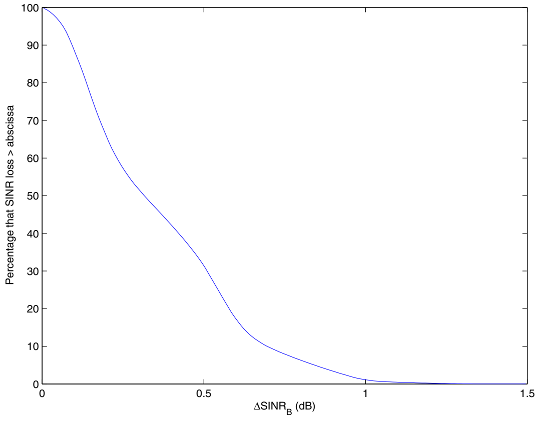

Fig. 6. Percentage of actual SINR_B loss (in dB) at the presence of three service requesting nodes.

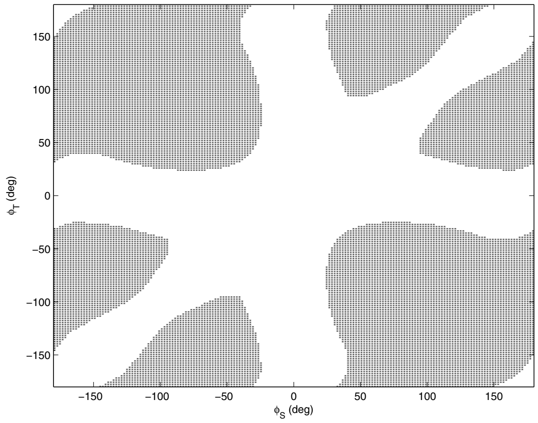

Fig. 7. DOA range where both requesting nodes can be accepted for communications.

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