A Brief Review of Opportunistic Beamforming

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Abstract

It is well proven that beamforming could significantly improve the performance of MIMO wireless system. However the feedback and complexity associated with the beamforming schemes has hindered their use. On the other hand one can use multiuser diversity, which is a form of diversity inherent in a wireless network, provided by independent time-varying channels across the different users to achieve if not most some of the benefits associated with beamforming. The diversity benefit is exploited by tracking the channel fluctuations of the users and scheduling transmissions to users when their instantaneous channel quality is near the peak. The diversity gain increases with the dynamic range of the fluctuations and is thus limited in environments with little scattering and/or slow fading. In such environments, it has been proposed that the introduction of fluctuations at the transmitter could improve the overall schemes performance. The scheme is named opportunistic beamforming and it has been shown that true beamforming gains can be achieved when there are sufficient users, even though very limited channel feedback is needed.

I. Introduction

Diversity can be obtained over time (interleaving of coded bits), frequency (combining of multipaths in spread-spectrum or frequency- hopping systems) and space (multiple antennas). The basic idea is to improve performance by creating several independent signal paths between the transmitter and the receiver. To maximize the total information-theoretic capacity, it has been shown that the optimal strategy is to schedule at any one time only the user with the best channel to transmit to the base station. Diversity gain arises from the fact that in a system with many users, whose channels vary independently, there is likely to be a user whose channel is near its peak at any one time. Overall system throughput is maximized by allocating at any time the common channel resource to the user that can best exploit it (Varying fading channel information is assumed to be tracked at the receiver and fed back to the transmitters). Multi user diversity can also be thought of as a form of selection diversity. There is a need for a scheduling algorithm within a system that exploits multiuser diversity to ensure fairness across users.

II. **Multi User Diversity and Scheduling**

As outlined in the introduction multiuser diversity could significantly improve a wireless networks performance. Let's assume that both the transmitter and the receivers can perfectly track the fading processes , then we can view this downlink channel as a set of parallel Gaussian channels, one for each fading state. The sum capacity of this channel, defined by the maximum achievable sum of long-term average data rates transmitted to all the users, can be achieved by a simple time division multiple access (TDMA) strategy: at each fading state, transmit to the user with the strongest channel. Fig. 1 intuitively describes the idea behind multi user diversity, where the green channel outlines the strongest channel amongst a number of users. It has been demonstrated in [1], [2] that with moderate number of users, the sum capacity of the fading channel is greater than that of a nonfaded channel. This is the multiuser diversity effect: in a system with many users with independently varying channels, it is likely that at any time there is a user with channel much stronger than the average SNR. By transmitting to users with strong channels at all times, the overall spectral efficiency of the system can be made high, significantly higher than that of a nonfaded channel with the same average SNR.

The system requirements to extract such multiuser diversity benefits are as follows: first each receiver tracking its own channel SNR, through, say, a common downlink pilot, and feeding back the instantaneous channel quality to the base station. Secondly the ability of the base station to schedule transmissions among the users as well as to adapt the data rate as a function of the instantaneous channel quality. This brings us to the second issue that a system that employs multiuser diversity needs to deal with.

Scheduling plays an important role to ensure that delay is kept to a minimum on the other hand the system is fair. In the ideal situation when users fading statistics are the same (figure 2), the strategy above maximizes not only the total capacity of the system but also the throughput of individual users. However, in reality, the statistics are not symmetrical (figure 3). Therefore the challenge is to address these issues while at the same time exploiting the multiuser diversity gain inherent in a system with users having independent, fluctuating channel conditions. In figure 2, the two users have identical fading statistics. Thus, the scheduling algorithm reduces to always picking the user with the highest requested rate. In figure 3 one users channel is much stronger than the other users on the average, although both channels fluctuate due to multipath fading. Always picking the user with the highest requested rate means giving all the system resources to the statistically stronger user and would be highly unfair. In contrast, under the proposed scheduling algorithm, users compete for resources not directly based on their requested rates but only after normalization by their respective average throughputs. The user with the statistically stronger channel will have a higher average throughput. Thus, the algorithm schedules a user when its instantaneous channel quality is high relative to its own average channel condition over the time scale . In short, data is transmitted to a user when its channel is near its own peaks.

One example of a scheduling algorithm that meets the above criteria is the work done in the context of the downlink of IS-856 system, operating on a 1.25 MHz IS-95 bandwidth. This system keeps track of the average throughput $T_k(t)$ of each user in a past window of length t_c . In time slot t, the scheduling algorithm simply transmits to the user with the largest

$$\frac{R_k(t)}{T_k(t)} \tag{1}$$

where $R_k(t)$ is the requested data rate [1].

III. **Opportunistic Beamforming**

Traditionally, channel fading is viewed as a source of unreliability that has to be mitigated. In the context of multiuser diversity, however, fading can instead be considered as a source of randomization that can be exploited. This is done by scheduling transmissions to users only when their channels are near their peaks. The larger the dynamic range of the channel fluctuations, the higher the peaks and the larger the multiuser diversity gain. In practice, such gains are limited in two ways. First, there may be a line-of-sight path and little scattering in the environment, and hence the dynamic range of channel fluctuations is small. Second, the channel may fade very slowly compared to the delay constraint of the application so that transmissions cannot wait until the channel reaches its peak. Figure 4 demonstrates how a system taking advantage of multi user diversity is capable of providing insignificantly higher performance improvement in a mobile (fast fading environment) compared to a fixed (slow fading environment) user.

Opportunistic beamforming is designed around this concept. By introducing fluctuations at the multiple antennas available at the base station, the system ensures that at any given time slot t one user's randomly selected coefficients closely match the actual beamforming coefficients thus giving the overall algorithm the name opportunistic beamforming. Figure 5 demostrates the idea behind the opportunistic beamforming approach. Consider a system consisting of N transmit antennas at the base station. In time slot t, the same block of symbols is transmitted from all of the antennas except that it is multiplied by $\sqrt{\alpha_n(t)}e^{j\theta_n(t)}$ a complex number at antenna n, for $n = 1, ..., N$, such that $\sum_{n=1}^{N} \alpha_n(t) = 1$, preserving the total transmit power. Figure 6 demonstrates the performance gain provided by a system taking advantage of opportunistic beamforming.

IV. Conclusion

Multiuser diversity has the potential to improve the performance of wireless networks by using the fluctuations inherent in a fading channel. However the overall multiuser diversity can be significantly increased from a theoretical point of view by introducing fluctuations at multiple antennas located at the base station or the mobile user. However it is important to note that there are no actual tests of the performance gains of such a system and it is also a bit naive to believe that random fluctuations introduced at the receiver can provide such system performance gains, unless many theoretical assumptions are made. Furthermore figure 7 demonstrates how the delay associated with a system using opportunistic beamforming could significantly increase in a fast fading environment, to a point where the whole system could stop functioning accordingly. Therefore it is the reviewers and authors opinion that system provides a theoretically new approach, however realistically the system may not ever be deployed.

References

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[3] M. Kobayashi, G. Caire, & D. Gesbert, "Transmit Diversity Versus Opportunistic Beamforming in Data Packet Mobile Downlink Transmission," , vol. 51, no. 5, May 2005.

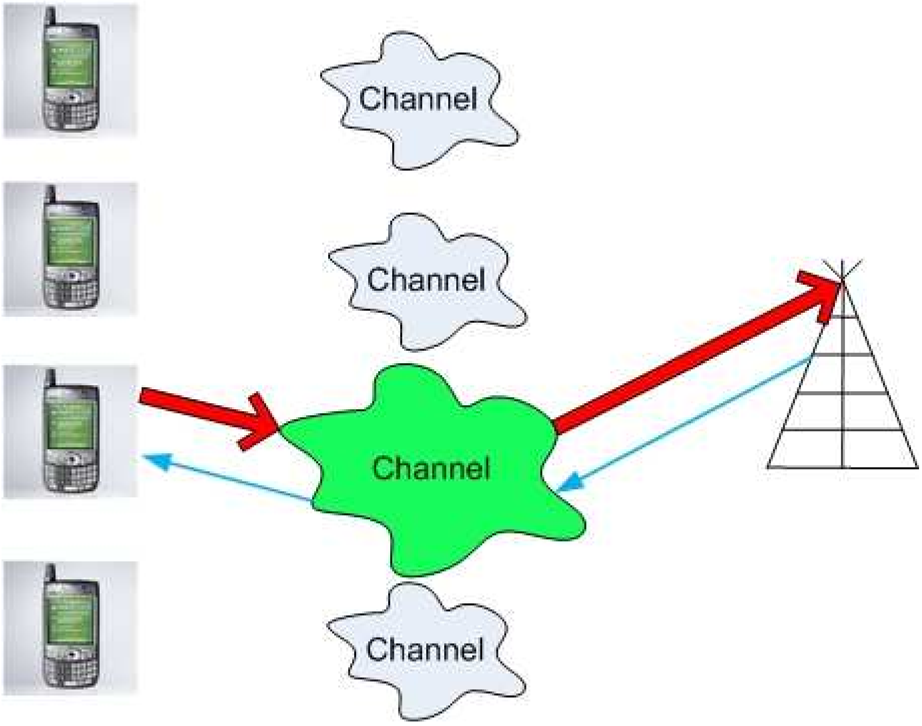

Fig. 1. Multi user diversity provides transmission to the user with the best channel at any given time.

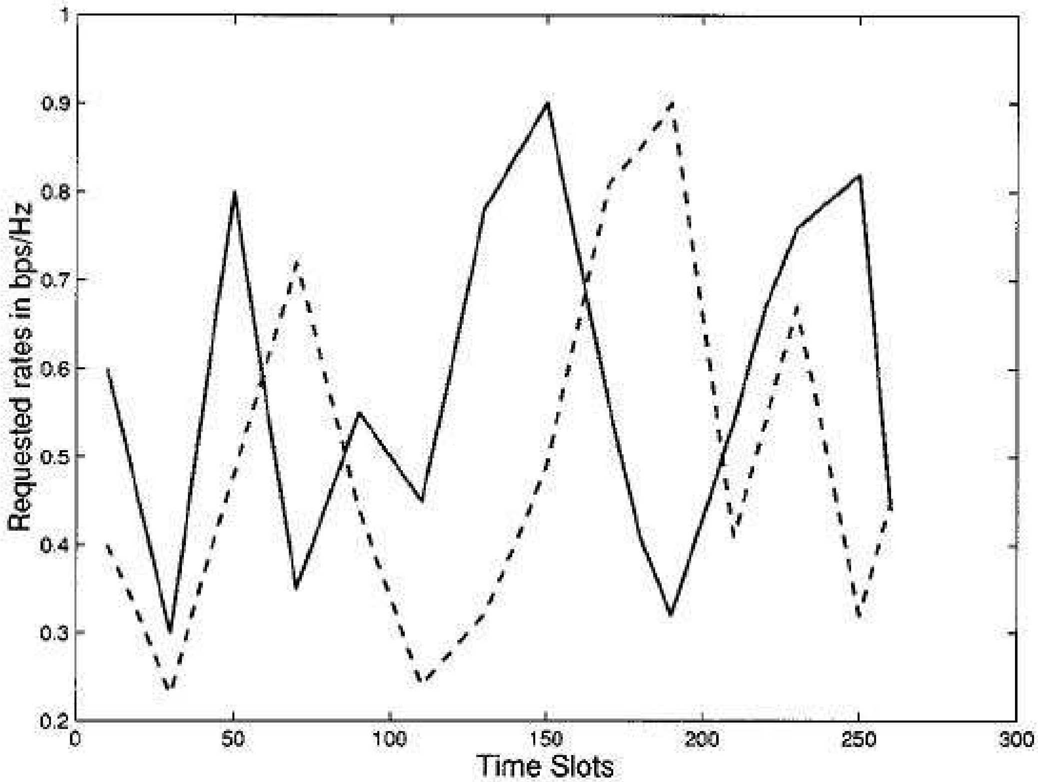

Fig. 2. For symmetric channel statistics of users, the scheduling algorithm reduces to serving each user with the largest requested rate. [1]

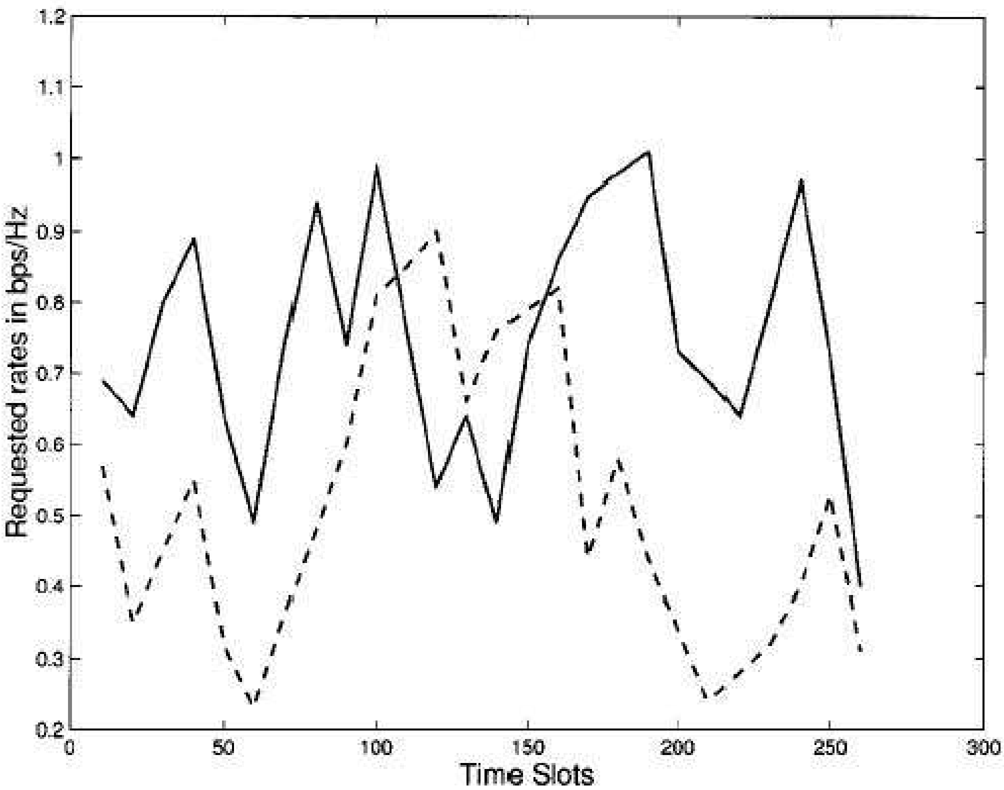

Fig. 3. In general, with asymmetric user channel statistics, the scheduling algorithm serves each user when it is near its peak within the latency time scale t_c. [1]

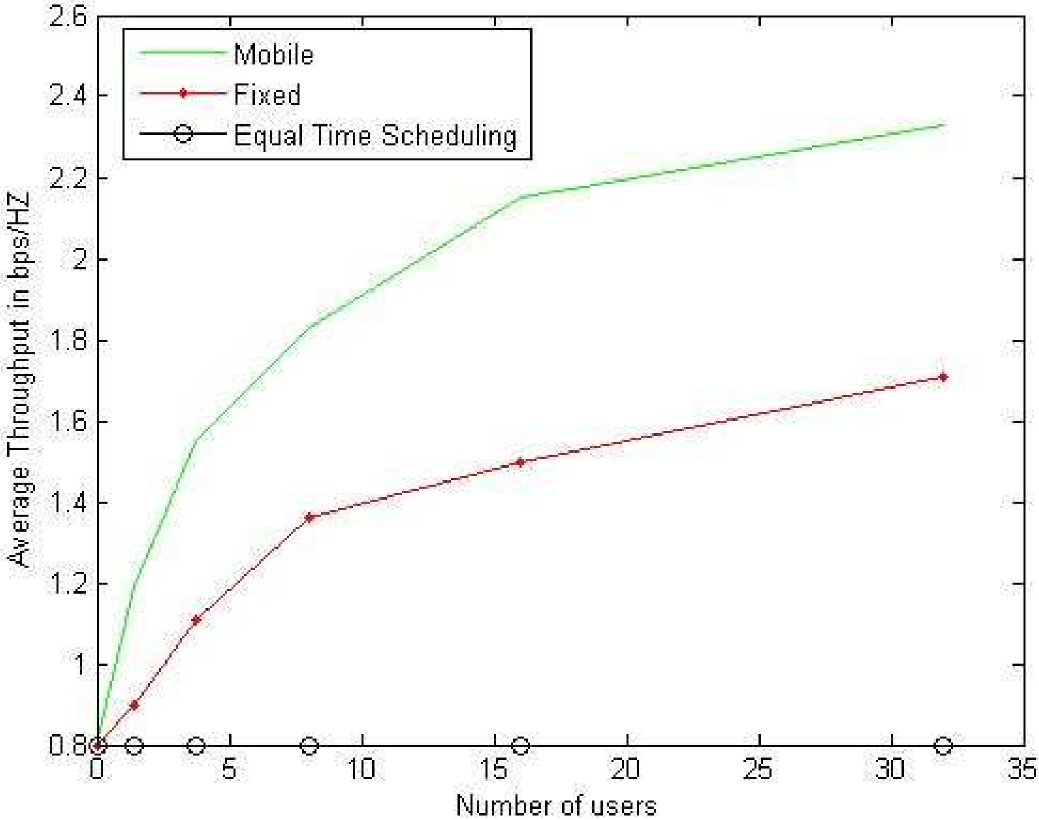

Fig. 4. Multiuser diversity gain in fixed and mobile environments. [1]

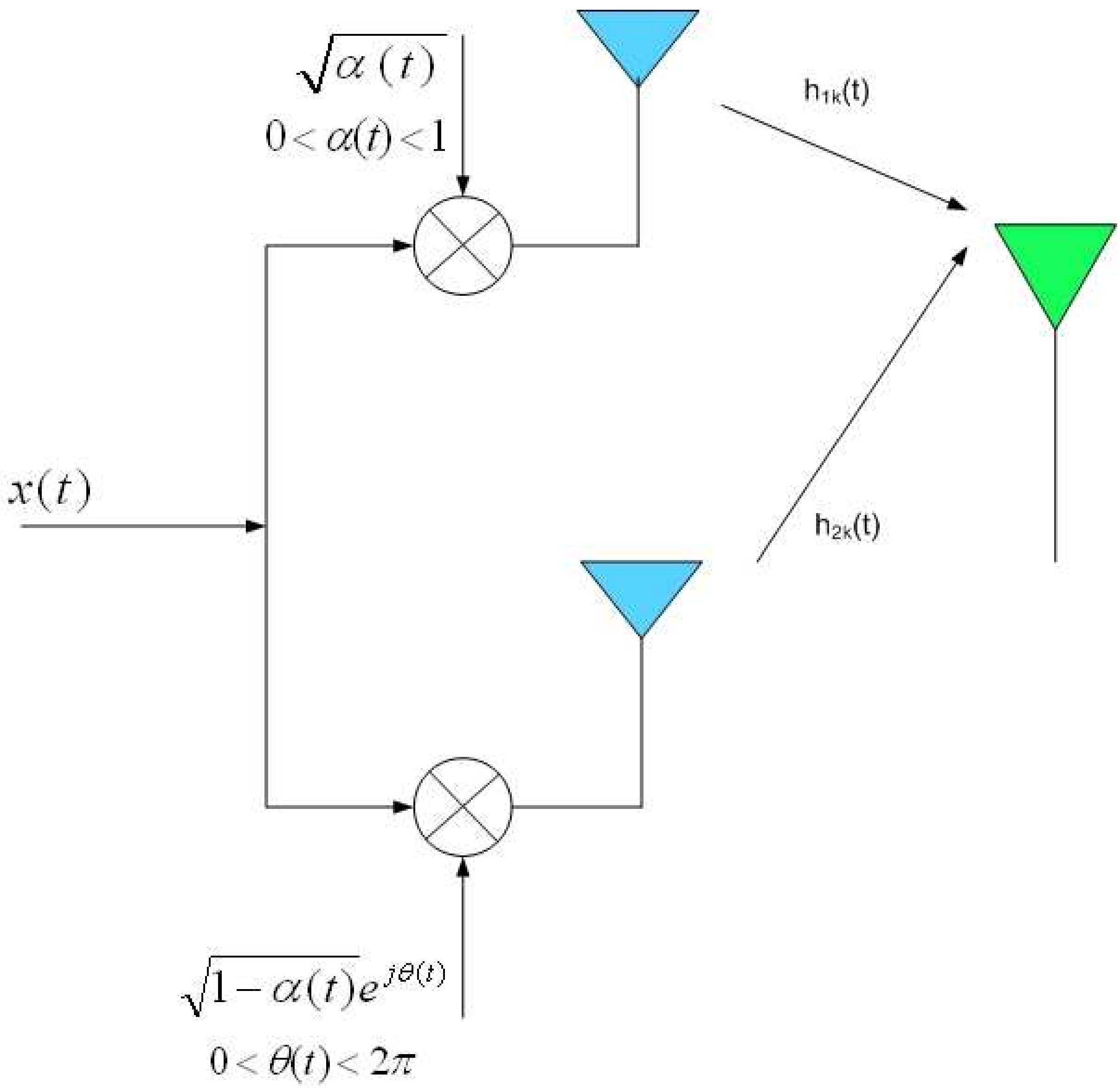

Fig. 5. The same signal is transmitted over the two antennas with time-varying phase and powers. [1]

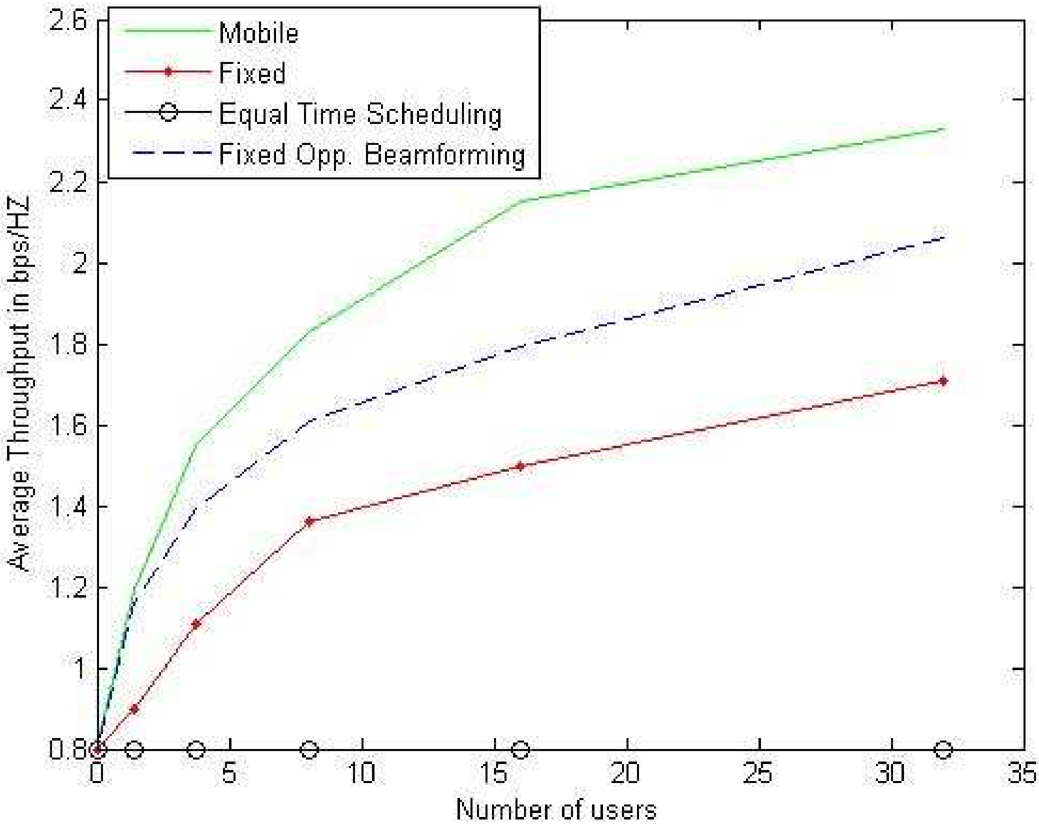

Fig. 6. Amplification in multiuser diversity gain with opportunistic beamforming in a fixed environment. [1]

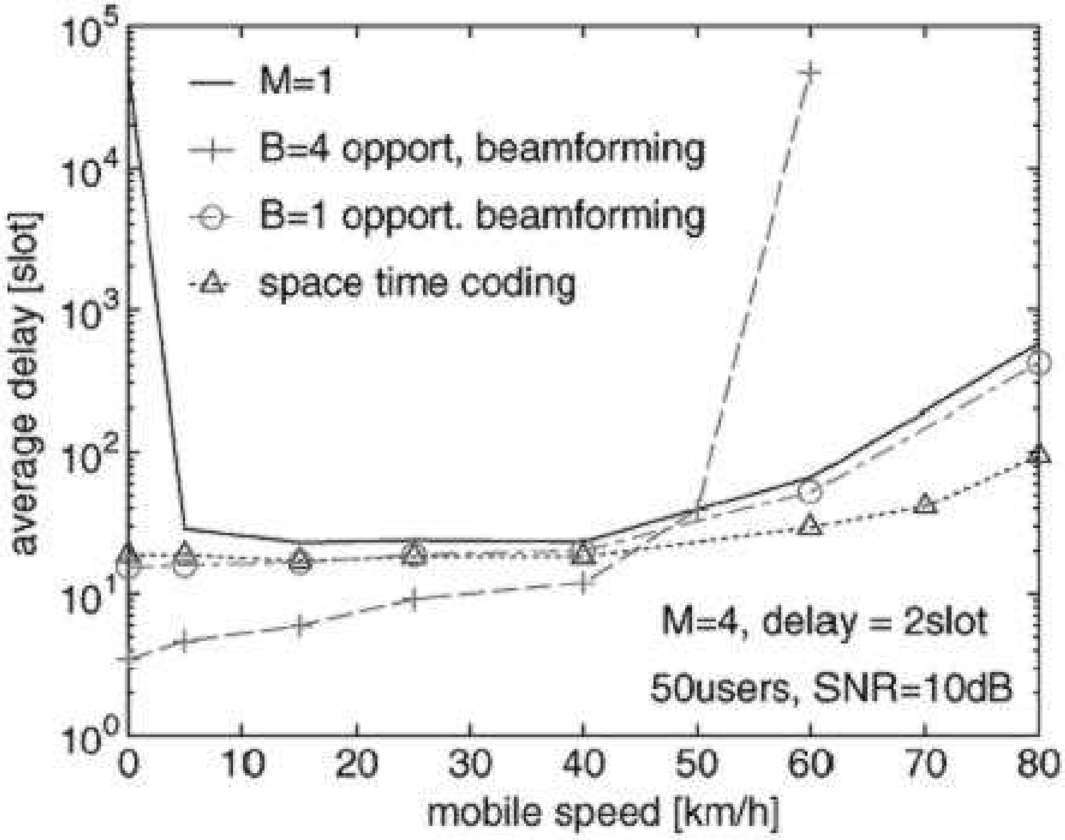

Fig. 7. Average delay versus mobile speed for the case of $K = 50$ users and $M = 4$ transmit antennas. The cases of random beamforming with $B = 1$ and $B = 4$ beams, and STC are compared. The case $M = 1$ (single antenna) is also included for comparison. [3]