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On the uplink outage throughput capacity of hybrid wireless networks with Massive MIMO

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ABSTRACT

In this paper, we investigate theoretical transmission capacity limit of the uplink hybrid wireless network under infrastructure mode. Massive MIMO technology is assumed to be equipped on the base station to further increase the whole network throughput. Multi-user MIMO is preferred over Point-to-Point MIMO to achieve improved scalability and simplify UE design. Another perspective of this paper is to include the fading effect on capacity. Under favorable propagation condition, Massive MIMO greatly mitigates small scale fading effect between each user and base station antenna. Then closed-form outage capacity over large scale fading channel is derived in both low SNR and high SNR scenarios.

1. Introduction and motivation

Hybrid wireless network becomes a hot research topic as the fast evolution of wireless communication systems. It is known that the wireless ad-hoc network (WANET) is a wireless network without backbone support. The decentralized feature makes ad-hoc network flexible for certain applications. It allows nodes joining the network dynamically without paying the cost of complex infrastructure. However, the drawbacks of pure ad-hoc networks are previous: less connection stability and signal strength issues for long range communication yield to lower throughput than infrastructure supported networks. Therefore, placing several wired interconnected base stations in ad-hoc network makes sense in terms of improving the whole network performance. Such infrastructure supported ad-hoc network is called hybrid wireless network [1] which takes advantages of both ad-hoc and infrastructure networks. The network topology is shown in Fig. 1.

Throughput capacity is the key element to analysis the performance of hybrid networks. Channel capacity, indicates how much data could be reliably transmitted over communication channel, eventually depends on what channel model applies. For example, the capacity of AWGN channel is essentially different from fading channels. For AWGN channel, transmitter could send out data at a positive rate while having desired very small error probability. Fading channel cannot guarantee to achieve this as long as the probability that channel in deep fading is non-zero. In slow fading scenario, outage capacity is always considered as it assumes that at a given rate R at which transmitter encodes data, whatever coding scheme used, the error probability cannot be made arbitrarily small. In other words, reliable communication occurs when the random channel gain is strong enough to support the desired rate R. Otherwise, outage happens when capacity drops below R in deep fading situation. For fast fading scenario, channel cannot remain constant over symbol coherent period. Since codeword span over several coherent period, we can use block-fading model that consider several parallel sub-channels fade independently. The capacity can be assigned with positive value by coding over a large number of coherence time intervals in order to average independent fading of channels [2].

A lot of research works has been done. Gupta and Kumar [3] initiatively studied scaling law of a random ad-hoc wireless network. When nodes are randomly placed in the network and they randomly choose a destination, the per-node capacity is shown to be $\Theta(\frac{W}{\sqrt{n \log n}})$ as the number of nodes n tends to infinity, where n is the number of nodes and W (the same below) is the transmitting rate each node is capable of using a fixed range. In [4], with b base stations and n nodes settings, the author proves that in order to achieve infrastructure gain, b should grow at least faster than $\sqrt{\frac{n}{\log n}}$ and the maximum throughput scales as $\Theta(bW)$ which increases linearly with the number of base stations. The scaling law of data transmission limit of hybrid wireless networks is studied in [5,6]. Squared cell model is assumed with b base

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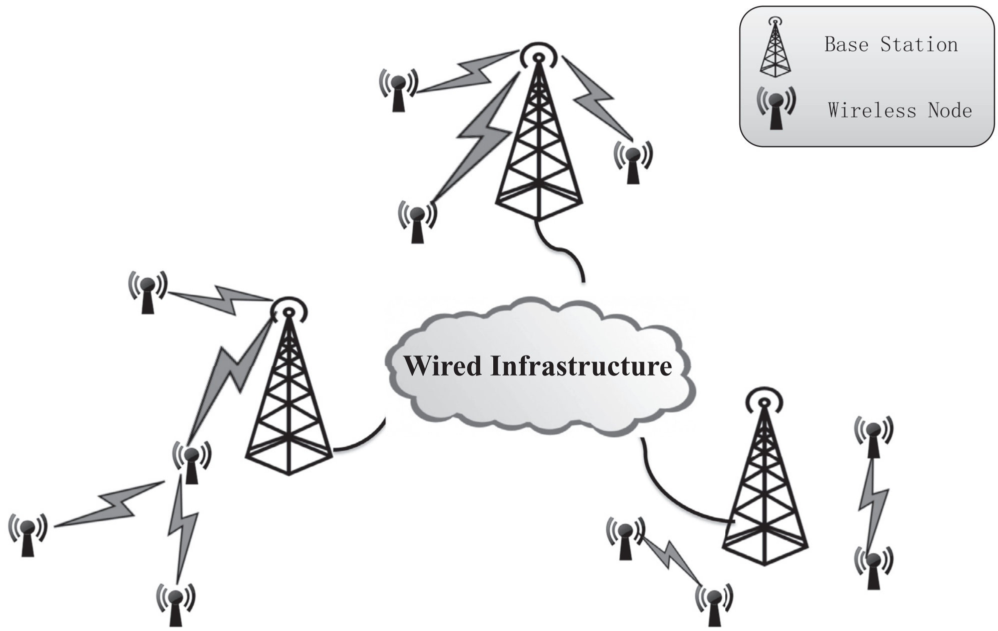

Fig. 1. Hybrid wireless network.

stations and n wireless nodes and fading environment is considered. The per-node outage throughput capacity over Nakagami-m fading channel scales as $O(\log[(\epsilon^{\frac{1}{m}})^{\frac{b}{n}}\frac{n}{b}]W_1)$ under ad-hoc mode and $\Theta(\frac{b}{n}\log(\epsilon^{\frac{1}{m}}\frac{n}{b})W_2)$ under infrastructure mode, where W_1 is the bandwidth shared by ad-hoc transmission and uplink infrastructure transmission and W_2 is bandwidth assigned for downlink infrastructure transmission.

In terms of Massive MIMO implementation under hybrid wireless networks, channel capacity could be very different from previous scenario. Massive MIMO capacity is studied in [7,8]. In this paper, considering using Massive MIMO for hybrid wireless network infrastructure to further improve system performance, we focus on studying how the uplink outage capacity scales with number of base stations b, number of users n, as well as large number of antennas M on the base station. Our analysis relies on deriving the outage capacity in closed-form expression including the variables aforementioned.

The rest of this paper is organized as follows: in Section 2, we introduce hybrid wireless network model and Massive MIMO implementation. In Section 3, we provide some preliminary knowledge for future derivation. In Section 4, we derive uplink throughput outage capacity under infrastructure transmission. In Section 5, we draw the conclusion.

2. Network modeling

2.1. Hybrid wireless network model

The following hybrid network model is considered throughout this paper:

1. The network consists of n nodes and b base stations totally.
2. The whole area has size n and is evenly divided into b hexagonal cells with unit density. Thus cell has distance $c = \sqrt{\frac{2\sqrt{3}}{3}\frac{n}{b}}$ between parallel sides (see Fig. 2).
3. Each cell contains only one base station which is placed in the center. There exists $K = \Theta(\frac{n}{b})$ users uniform circularly placed surrounded the base station within each cell. Each node in the same cell has the same distance d_k to the base station. Nodes placement are shown in Fig. 3.

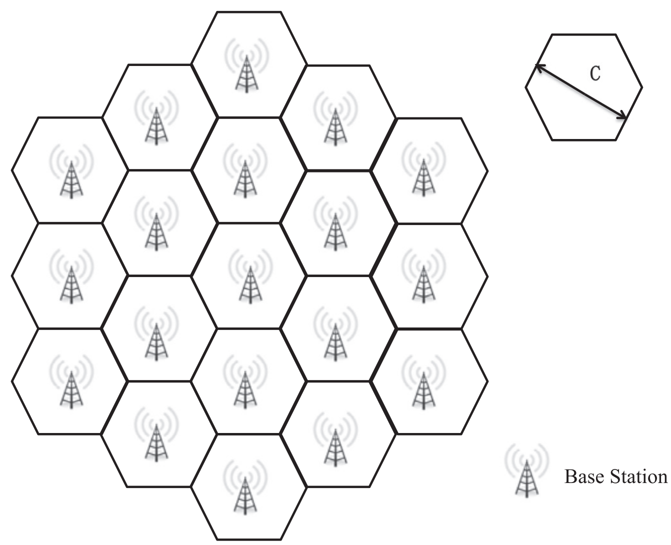

Fig. 2. Hexagon cell with distance c between parallel sides.

4. We assume all base stations are wired interconnected to form an infrastructure with unlimited bandwidth. Base stations neither consume nor generate data and they only serve as traffic relays compared to nodes.
5. For the purpose of studying the scaling law of number of base stations and nodes in the network, $b = o(\frac{n}{\log n})$ is assumed that b increases at a slower rate than n. Study [4] shows that in a probabilistic routing strategy, a node chooses between infrastructure and ad-hoc mode according to some probability. For example, if b grows slower than $\sqrt{\frac{n}{\log n}}$, the maximum throughput capacity behaves asymptotically same as pure ad-hoc networks which means no real benefit for using infrastructure. If b grows faster than $\sqrt{\frac{n}{\log n}}$, maximum capacity increases linearly

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