Link Layer Capacity of MIMO Ad Hoc Network with Noise Environment

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Abstract— MIMO Ad Hoc Networks are expected to provide broadband wireless service parallel to wired counterpart and may be replaced for emergency services. MIMO holds the significant promise to maximize the resource uses. In this paper, the channel capacity analysis is made based on a model MIMO Ad Hoc network assuming that each link occupies a geometric area that characterizes the amount of spatial resources occupied by a link. The amount of spatial resource of each link is considered with the interference effects that inflicts on other links. The link layer capacity is investigated here considering the noise effect for the above MIMO Ad Hoc Network employed in the noisy environment. The cumulative distribution function of signal to noise ratio with interference effect is calculated first and then throughput of the communication link is derived. Finally simulated results are shown considering different number of nodes. This result helps to find out number of active links and data rates within an area.

Key words: MIMO, Link Layer Capacity, Co-Channel

I. INTRODUCTION

A mobile ad hoc network (MENET) represents a system of wireless mobile nodes that can freely and dynamically self-organize into network topologies. It is basically peer-to-peer network of hosts connected by wireless links.[1,2] It has been observed that the MIMO technologies help to boost the significant advances and lead to potential break through towards robust Ad Hoc Network design. Wireless data rate for multiple-input-multiple-output (MIMO) systems with multiple antennas at both transmitter and receiver obey the following fundamental theoretical limit:

$$C = M * B * \log(1 + SNR) \quad (1)$$

Where M=min {M_t, M_r}, and M_t , M_r are the number of antennas at transmitter and receiver, respectively, provided that an improvement of the rate factor by M[3].

MIMO system uses multiple transmitters and receivers to create additional paths or radio channels for the wireless transmission where each path operates independently as the paths are orthogonal in communication channels and the receiver recognizes this [4]. This requires a high-signal to noise ratio which uses sophisticated algorithms to separate the paths which overlap in time and frequency. The key benefit of MIMO is that it offers significant increases in data throughput and link range without additional bandwidth or transmit power [5]. It achieves this by higher spectral efficiency (more bits per second per Hertz of bandwidth)[6] and link reliability or diversity (reduced fade)[7]. For noise free channel, the average amount of information received would be H(X) bits per symbol, when interference and noise are added to the receiving signal, then amount of information received by the receiver is the ergodic mutual information between the channel input and output which can be expressed in terms of two conditional entropies: $\mathrm{E}(\mathrm{H}(\mathrm{y_k}))$ known as the self-entropy of the channel without any knowledge about the received signal $\mathrm{y_k}$and $\mathrm{E}(\mathrm{H}(\mathrm{y_k}/\mathrm{x_k}))$ known as the conditional entropy of the channel with the knowledge of a particular received signal $\mathrm{y_k}$. The mutual information $\mathrm{I(X;Y)}$ between the channel input and output is the amount of uncertainty obtained by difference between the above two entropies and is given as,

$$I(X;Y) = E(H(y_k) - H(y_k / x_k))$$
$$= E(H(y_k) - H(n))$$
$$= E(\log \det(I + \eta_k H_{kj} R_j H_k^H (\sum_{j \neq k} \eta_{kj} H_{kj} R_j H_{kj}^H + \sigma^2 I))) \quad (2)$$

Here the element H is a $N_T \times N_R$ matrix that has a complex Gaussian distribution. $\eta(k)$ is the $N \times 1$ additive white Gaussian noise vector with zero mean and matrix covariance C_w.

If the set of signals are independent and excited by different transmitters and detected by receiver then the element H will be independent as well. It is observed that if these two conditions are satisfied, the maximum mutual information will be obtain and that will be MIMO channel for a given transmitter power. The ergodic capacity for channel matrix H is given as:

$$C = E_H \left\{ \log_2 \det \left(I_{NR} + \frac{P_T}{P_N N_T} HH^* \right) \right\} \quad (3)$$

We have considered the large network so that homogeneous channel and interference conditions occurred. Under this condition throughput of each link is same and summation of that is equivalent to channel capacity. We assume that the network is quasi stationary and outage capacity of the channel is

$$C_K = \log_2\{\det(I_{N_r} + \frac{\rho}{N_t} H_K H_K^*)\}$$

For K burst or hops.

The random channel matrix H_K is varying from one burst to the next, C_K will itself vary accordingly.

In this paper we should find out the link failure due to interference and also interference cancellation between MIMO links.

This gives us the information about the failure of the transmission as well as success or throughput of the probability of the output of the network.

Finally the link layer capacity is calculated and simulated to get the results.

II. SYSTEM MODEL AND CHANNEL CAPACITY

The fig1shows the system model of mobile Ad Hoc Networks with multiple antennas. The mathematical analysis of this model is done with some assumptions. We assumed here that the MIMO nodes are uniformly distributed with in the network area, and assume that each link between the transmitting and receiving antenna has same statistical characteristics. The topology of the network changes dynamically and distributed over the nodes forming the networks. Here all transmitting nodes are connected to the receiving nodes using mobile links. Let us consider that the node R is the receiving node where the other nodes are transmitting nodes without loss of generality the link H_R is receiving the signal and other link are transmitting at a same time resulting the co-channel interference on link H_R. Under this condition the data received by the receiving link is the superposition of the desired signal interference and noise which is given as follows.

$$Y = \sqrt{\alpha_0 \rho_0} H_O x_o + \sum_{k=1}^{K} \sqrt{\alpha_k \rho_k} H_k x_k + n_0 \quad (4)$$

Here H_k is an m x m channel matrix which is representing the channel fading from the transmitter of the *k*th link to the receiver of tagged link.

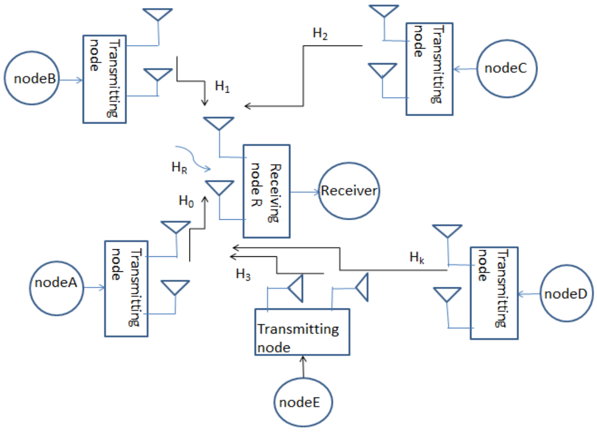

Fig. 1: Model network for MIMO Ad Hoc communication

III. LINK CAPACITY WITH SNR

Ad Hoc network works in an interference limited environment where an active link will transmit only one data stream at a time to avoid excessive interference with other links. The single data stream to be transmitted to such a node for which SNR will be maximized . The throughput capacity of the link is the total data rate delivered successfully through all single hop links[8]. If the active link transmits at data rate R, then successful transmission will be possible and SNR will be maximize when SNR of the receiver side is higher than the threshold receiver which is the function of data rate Q. Consider the channel to limited to power and bandwidth, the data rate Q and SNR value are given by

$$Q = \log_2(1 + SNR_{th}) \quad (5)$$

This generic equation is the function of all the links. Now, if we consider total (x+1) number of links where one links is acting as the receiver and rest x links are acting as the interfering links.

The message which has SNR value less than the threshold SNR will not processes through the channel. Hence the number of failure of signal per message is

$$P_{out} = P_{rop}(SNR_0 < SNR_{th}) \quad (6)$$

The message to be process by channel $(1 - P_{out})$ and data rate is R. Therefore the throughput of the communication link is

$$T = (1 - P_{out})R \quad (7)$$

The Poisson distribution is used to calculate the probability of active links in the network which is given by

$$P = \frac{e^{-\mu}\mu^{(x+1)}}{(x+1)!} \quad (8)$$

When x is the number of interfering links and one is the active link acting as the receiver may be called the tagged link where μ is the mean or average number of active links is equal to

$$\mu = \rho_0 \pi \frac{D^2}{4} \quad (9)$$

Where D is the diameter of the network and ρ_0 is the number of links per unit area.

Now we know the data rate, number of active links and throughput. So we can write the link layer throughput capacity as

$$C = \sum_{x=0}^{\infty}(x+1)(1 - P_{out})R \frac{e^{-\mu}\mu^{(x+1)}}{(x+1)!} \quad (10)$$

IV. SIMULATION AND NUMERICAL RESULTS

We have simulated the network to find the outage capacity of MIMO channel will different number of antenna sets. The nodes are assumed to be quasi stationary from one burst of data transmission to the next one. We have assumed that CSI at each receiving nodes are known that is the receiver knows the channel matrix h_k from all the interfering nodes. The receiving node estimates the channel from interference of the active link density which is directly related to transmission probability. The variation of cumulative probability density which is throughput capacity for the link layer with SNR is shown in fig2 for 4 interfering nodes. Up to a certain level of SNR the link layer capacity is low and after 20 db the capacity increases and reaches to a certain value rapidly. With high SNR the interference cancellation occurs for which the cumulative distribution increases. In fig3 the link layer capacity or the transmission throughput per unit area are shown with the active number of links. In this simulation the channel monitory range is taken as three units. The maximum throughput depends on the channel monitoring range.

The fig 4 shows the variation of the capacity with the active links for the restricted antenna of 6 limits.

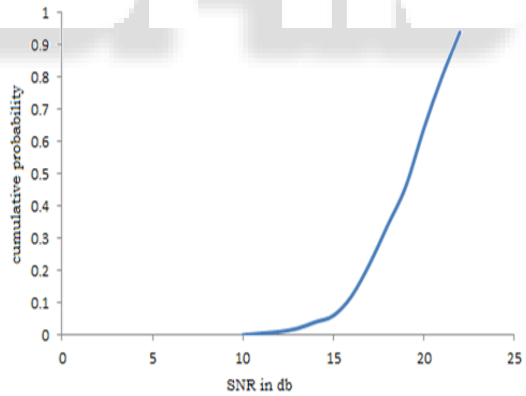

Fig. 2: CDF vs SNR for 4 interfering nodes

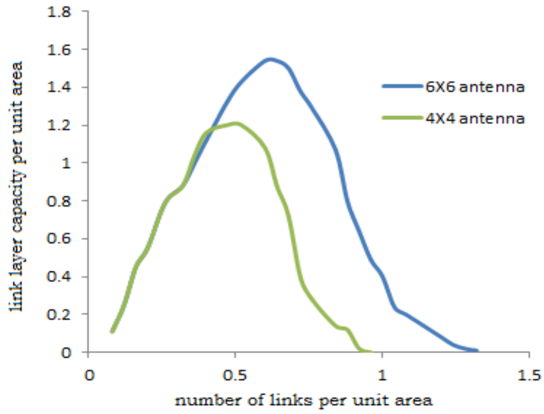

Fig. 3: Throughput capacity vs number of links

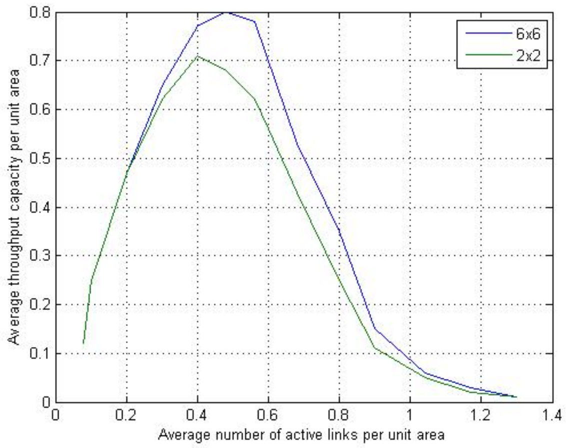

Fig. 4: Throughput capacity of the channel with restricted monitoring range of 6 units

In case of large channel estimation range the channel capacity is higher than the low range coverage. From this fig but from we assume that in restricted zone the receiving node only estimates the channel from interference. Out of the restricted zone the interference is treated as noise. When we restrict the channel-monitoring range, the maximum throughput capacity is slighted reduced from its original value.

V. CONCLUSION

In this paper we simulated the Ad hoc network with multiple antennas to investigate the link layer throughput with known CSI at the receiver. The integration of the PHY layer co channel interference, the cancellation capability and MAC layer throughput capacity in the MIMO Ad Hoc network are done here. In this paper the throughput capacity, link layer capacity are evaluated and simulated to make the comparison. The effect of active number of links on the link layer capacity for different monitoring range is analyzed. In future we used the concept of allocation of degree of freedoms, D_OF_S to solve the MAC layer interference and cross layer scheduling.

REFERENCES

[1] Iwata et al “Scalable Routing Strategies for Ad hoc Wireless Network”IEEE Journal on Selected Area in Communication ,Special Issues on Ad-hoc Networks Aug,1999 pp1369-1379.
[2] S.R.Das,R.Castaeda,J.Yan and R.Sengupta, “Comparative Performance Evaluation of Routing Protocol for Mobile Ad hoc Networks” in Proceeding of 7th International Conference on Computer Communication and Networks(IC3N), october 1998 pp 153-161.
[3] Viktor V. Zaharov and Houssain Kettani, “MIMO Ad Hoc Network Performance in the Presence of Co-channel Interference,”published in Computer Research and Development, 2010 Second International Conference on 7-10 May 2010K. Elissa, “Title of paper if known,” unpublished.
[4] RFC 802.11n Standard for MIMO communication. www.802.1n standard.
[5] Chao Liang, Student Member, and Kapil R. Dandekar, “Power Management in MIMO Ad Hoc Network:A Game-Theoretic Approach,” IEEE transaction on wireless communications,vol.6. no.4, April2007.
[6] Jialing Zheng and Maode Ma, “QOS-Aware Cooperative Medium Access Control for MIMO Ad-Hoc Network,” IEEE communication Letters, vol14, no1, January 2010.
[7] L. Zheng and D. N. C. Tse, “Diversity and multiplexing: a fundamental tradeoff in multiple-antenna channels, ” IEEE Trans. Inf. Theory, vol. 49,no. 5, pp. 1073–1096, May 2003.
[8] A. J. Paulraj, D. A. Gore, R. U. Nabar, and H. B61cskei, "An Overview of MIMO Communications: A Key to Gigabit Wireless,” Proc. IEEE, vol. 92, no. 2, pp. 198 218, Feb. 2004.

