Joint Scheduling and Spreading Gain Optimisation for the Energy Consumption in CDMA-TDMA Based MANETs

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***Abstract*— This paper proposes an algorithm that combines the qualities of code division multiple access (CDMA) and time division multiple access (TDMA) to minimise the total network energy. Energy in CDMA system depends on transmission power and transmission time. It can be shown that transmission time directly proportional to processing gain of the transmitter-receiver pair. As a result minimisation of total network energy depends on the processing gain and transmission time. The choice of processing gain depends on the interference level that a receiver needs to overcome to receive its intended signal. On the other hand the interference level at each receiver depends on the distance between the receiver and all other transmitters around it, apart from its intended transmitter. In this section, we investigate the impact on network energy by forming subsets of transmitter-receiver pairs. Formation of these subsets depends on the maximum processing gain that can be used for transmission as well as having maximum number of transmitter-receiver pair at each subset. TDMA is used to schedule the subsets and the communication channel employs CDMA. The results show that the proposed algorithm decreases total network energy by significant amount. As an extension of this algorithm this paper also address the impact of the total network energy by applying priory to individual nodes.**

I. Introduction

Energy is a hard constraint in Mobile Ad Hoc Network. In some situation it is not renewable at all. As a result minimising network energy is a prime concern in mobile ad hoc network. The choice of spreading gain is very important in CDMA based network. It describes one of the unique properties of spread spectrum waveforms. Processing Gain is used to improve interference immunity, low transmit power density and multiple simultaneous transmissions. On the other hand an increase in processing gain increases transmission time and total transmission power. For a dense neighbourhood processing gain and transmission power could be high enough to overcome interference in CDMA based network. As a result total network energy consumption will also be high. This motivates us to have a maximum limit for the spreading gain, which infact leads us to minimise the total network energy using combined CDMA TDMA operation.

CDMA is based on spread spectrum (SS)[1] techniques, in which all users share the entire bandwidth and transmit at the same time. A key feature of CDMA systems which has been adopted for third generation systems is that by changing the spreading gain, one can also vary the rate of the data to be transmitted over the channel. More precisely, a decrease in the Spreading Gain allows for the initial stream of data to be transmitted at higher rates. While this is a desirable feature, especially for transmitting real time applications which requires high data rates and/or small latency, the drawback of reducing the spreading gain is that it requires increased transmission power, raising the level of interference created in the network. As a result a good tradeoff between spreading gain and transmission power is required. In TDMA based system, the bandwidth is divided by nodes in time slots and access control is achieved by scheduling time slots for transmitters. In this paper we propose an algorithm to find an optimal group of nodes and schedule time slots to the group using CDMA on the communication channel. As a result different group of nodes will be assigned one time slot each, depending on certain constraints explained in section II.

Joint scheduling and power control algorithm are studied in [2]-[4]. In [2] authors approach consists of scheduling and power control phases. Scheduling phase eliminates strong interference by searching largest subset of nodes that satisfy ”valid scenario constraints”. These constraints are a node can not transmit and receive simultaneously, It does not receive from more than one neighbor at the same time, and when receiving from a neighbor the node is separated from other interferers by at least a distance D. This distance D is set to the frequency reuse distance.The algorithm is invoked slot by slot basis. Power control phase of this paper the authors [2] examined a cellular like solution that involves differing the user with the minimum SINR in an attempt to lower the level of Multiple Access Interference. It also makes the transmission power control problem similar to that of cellular systems. In addition to the constraints discussed in [2], authors in [3] proposes scheduling metric as a constraint to assign a slot to a link. The link with lower link metric has higher priority in the scheduling to occupy the time slot. In [4]authors addressed multicast transmission and proposed a distributed joint scheduling and power control scheme for multicast transmission.

Our main contribution in this work is to divide the whole network in such a way that the total energy consumption is minimum. It is well known that spreading gain and transmission power for a particular transmission in CDMA based system depends on the interference that a receiver needs to overcome, to receive its intended signal. Keeping this in mind we formulated an optimisation problem, where the cost function is the overall energy consumed in the network and the constraints are the acceptable signal to interference ratio for each node. It is observed that in some scenarios, where transmitters are close to any receiver other than its intended receiver spreading gain increases to a very high value. As a result, in this work we looked at the behavior of the network, in terms of energy consumption, limiting spreading gain to some positive value and breaking the total network into subsets, where each subset is allowed to transmit for one time slot each. This Joint Scheduling-Spreading Gain Algorithm enable us to decrease total energy consumption by a significant amount. The advantages and disadvantages of Joint Scheduling-Spreading Gain Algorithm is described in section II. Looking at the disadvantages of this algorithm we extend our research and further propose Joint Scheduling-Spreading Gain Algorithm with priority, where each node is associated with a priority depending on the number of times it was eliminated to transmit in 1st time slot. The aim behind this algorithm is to have fair scheduling among all nodes in the network. This algorithm also works well when mobility is considered, with the assumption that within one time slot the network state is same.

II. Assumptions and System Model

Let us define a neighborhood of $2M$ nodes, where, $\mathcal{M}_T \in (1, 2, \ldots, M)$ are the transmitters and $\mathcal{M}_R \in (1, 2, \ldots, M)$ are the receivers in the network. Furthermore, each transmitter $i \in \mathcal{M}_T$ want to simultaneously send packets to all the receivers $(1, \ldots, M) \in \mathcal{M}_R$. From the locations of the nodes and the propagation characteristics of the environment we can compute the channel gain matrix, $\mathbf{G}$, where, $G_{ij} \geq 0$ is the instantaneous gain between the transmitter i and the receiver j. Similarly we can also define $\mathbf{P}$ and $\mathbf{N}$, the transmitter powers and processing gains used by M transmitters, to transmit packets to all the M receivers.

Let us consider an area of $250m * 250m$, where all nodes are randomly distributed. At this stage, we also assume that all transmitters can directly communicate with any other receiver within this area via wireless medium and each node is communicating with a single neighbor only. i.e, no multihop transmission is required in the network. Routing is a subject of ongoing research and out of scope for this paper. Each node has the global knowledge of the position of all other nodes in the network, which is necessary to run the optimisation problem. The position of all other nodes in the network could be tracked by location discovery schemes [7]-[8]. Node mobility is not considered in this study. It is assumed that the network is stationary and the gain matrix is constant for each time slot duration. All time slots are equal in duration. The network uses two separate channels, one for data and one for control. The objective of this paper is to divide set $\mathcal{M}_T$ and $\mathcal{M}_R$ into subsets that minimize the total energy consumed by the network by finding optimum subsets of $\mathcal{M}_T$ and $\mathcal{M}_R$, such that all packets are received properly. Finding optimum subsets depends on the maximum processing gain permitted for a particular transmission in the neighborhood.

The paper is organised as follows: section II, describes joint scheduling-spreading gain algorithm in details. This is followed by joint scheduling-spreading gain algorithm with priority section III . A brief comparison between the proposed algorithms are shown in section IV. Simulation results are shown in section V. Finally, the conclusions are drawn in section VI.

III. Joint Scheduling-Spreading Gain Algorithm

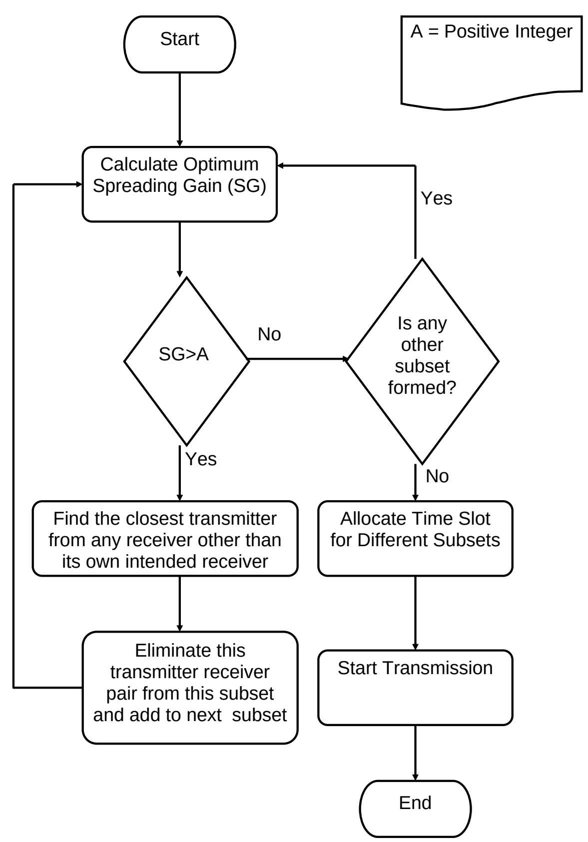

Fig. 1. Flowchart of the Joint Scheduling-Spreading Gain Algorithm

Joint scheduling-spreading gain algorithm is explained through flowchart in Figure 1. In this section we consider the algorithm to divide the transmitter receiver pairs into subset and this is done through energy optimisation problem [5] as follows:

$$\text{minimise} \quad F(\mathbf{P}, N) = N \sum_{i=1}^{M} P_i$$

subject to

$$\frac{P_{ij}G_{ij}}{\frac{1}{N}\left(\sum_{k=1,k\neq j}^{M} P_{ik}G_{ij} + \sum_{l=1,l\neq i}^{M}\sum_{k=1}^{M} P_{lk}G_{lj}\right) + \sigma^2} \geq \beta$$

Where σ^2 is the thermal noise power at the receiver. Furthermore, all the transmitted powers and the spreading gain of the system must be strictly positive. Hence,

$$\begin{aligned} P_i &> 0 \ \forall \ i \in \mathcal{M}_T \\ N &> 0 \end{aligned}$$

The solution of the above optimisation problem results in $2M+1$ equations with $2M+1$ unknowns, which we can solve for $\mathbf{P}$ and N.

$$\frac{-1}{\phi^2}\sum_{m=1}^{M} P_m + \beta\sum_{m=1}^{M}\lambda_m \sum_{k=1,k\neq m}^{M} P_k G_{km} = 0$$

$$\frac{1}{\phi} + \phi\beta\sum_{k=1,k\neq i}^{M}\lambda_k G_{ki} - \lambda_i G_{ii} = 0 \ \forall \ i \ \in \mathcal{M}_T$$

$$\phi\beta\sum_{k=1,k\neq i}^{M} P_k G_{ki} - P_i G_{ii} + \sigma^2\beta = 0 \ \forall \ i \ \in \mathcal{M}_T$$

The solution provides the optimum spreading gain and the transmitter powers for all transmitters. Here, it is worth to be mansion that transmission power control is automatically taken care of by the optimisation problem as we optimise total network energy.

The algorithm starts finding minimum spreading gain for the network and individual transmission powers for all transmitters in the network following the above optimisation problem. If spreading gain of the optimisation problem results lesser than some positive value then all nodes can transmit at the same time, otherwise the first node to be eliminated from transmission is the transmitter closest to any receiver other than its intended receiver. Elimination of this transmitter receiver pair will decrease the required spreading gain. This loop with the algorithm will be executed unless a set of transmitter receiver pair is found where the spreading gain upper limit is satisfied. All eliminated nodes will be considered for the next consecutive time slots. As a result all transmitter receiver pairs in the network will be divided into different subset and nodes in each subset will transmit in one time slot with spreading gain less than some positive value.

This algorithm could be invoked at the beginning of every time slot in order to cope with the interference level or at the end of all transmitters from all subset finishes transmission. Theoretically the later gives the optimal solution. The invocation time of this algorithm is very important. Let us first consider that a set of n nodes is divide into m subsets according to the Joint Scheduling-Spreading Gain Algorithm. These m subsets will transmit in m consecutive time slots. Hence, The results of the algorithm is true and optimum if within m consecutive time slots no other new transmitters are considered. In other words this result is true for m consecutive time slots and within this period no mobility, addition or deletion of nodes are considered within the network. So, we can conclude that if this algorithm is invoked at the end of m time slots, minimum total network energy is consumed but not a realistic solution in terms of mobile ad hoc network. It is much realistic to assume that this algorithm is invoked at the beginning of every time slot with the assumption that interference level at each receiver remains constant during one time slot. In this case this algorithm will find a subset from all transmitters to transmit in the next time slot, where spreading gain is less than some positive value. Mobility, addition and deletion of nodes could be taken into account at the beginning of every time slot. This ensures realistic approach, but lacks of fair scheduling. This means that a node may not get a chance to transmit at all because of new set with k nodes are formed within the network. To overcome this problem we propose Joint Scheduling-Spreading Gain Algorithm With Priority, as described in the following section.

IV. Joint Scheduling-Spreading Gain Algorithm With Priority

The aim of this algorithm is to find a set of k nodes that satisfies the spreading gain to be less than a predefined positive integer. The selection of these k nodes depends on the priority of the nodes and spreading gain constraints. A higher priority nodes gets prior chance to transmit. This algorithm is invoked at the beginning of every time slot. Each node enters in the network with priority Zero and for each elimination from transmission its priority is increased. This certainly implies that each time a node is eliminated form transmission it will have more chance to transmit in the next time slot. As this algorithm is invoked at the beginning of every time slot it takes into account mobility, addition and deletion of nodes within the network. Although multihop is out of scope for this paper but a probable advantage of this algorithm would be in multihop environment, where if an eliminated node moves from one neighborhood to another, its priority will not change. As a result transmission slot allocation for this algorithm depends on the number of time it was eliminated from transmission, instead of position of the node. In other words, fair scheduling can be achieved and node mobility can be considered in multihop environment. Other constraints remains same as discussed in Joint Scheduling-Spreading Gain Algorithm and must be satisfied too. Once a node transmits, its priority will reset to Zero. Figure 2 shows the flow chart for Joint Scheduling-Spreading Gain Algorithm With Priority algorithm.

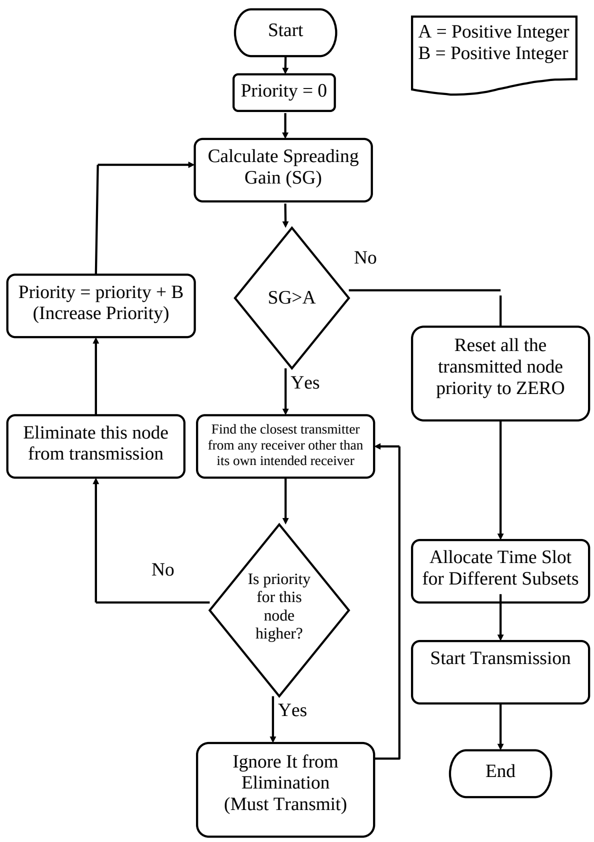

Fig. 2. Flowchart of the Joint Scheduling-Spreading Gain Algorithm With Priority

V. Simulation Setup

We considered a neighborhood of $2M$ nodes, with M transmitters and M receivers distributed in $250\,m * 250\,m$ meter area, where each node can directly communicate with any other nodes in the neighborhood. The simulation parameters and their values are summarized in table 1.

The free space propagation model is used to estimate the received signal strength assuming the transmitter and receiver have a clear, unobstruct line-of-sight path between them.The channel gain between transmitter i to receiver j can be calculated as,

$$G_{ij} = \frac{K}{d^2}$$

where, K is a constant based on free space propagation environment and d is the distance between transmitter and receiver.

In the simulations, The transmitting powers of all M nodes were estimated for a given processing gain N using the set of M equations based on the receiver SIR as follows:

$$\frac{P_i G_{ij}}{\frac{1}{N}\sum_{k=1,k\neq i}^{M} P_k G_{kj} + \sigma^2} = \beta \;\; \forall\, i \;\in \mathcal{M}_T$$

VI. Simulation Results

Figure 3(A) shows one of the random scenario used for simulation as an example to illustrate the potentials of Joint Scheduling-Spreading Gain Algorithm. Addition to this algorithm Joint Scheduling-Spreading Gain Algorithm With Priority also discussed, which basically finds a subset of transmitters to transmit in the next time slot and follows fair scheduling. Several sets of simulations were carried out for different node distributions and number of nodes within neighborhood. All the simulation result sets follow similar results as the one shown in Figure 3(B), Figure 3(C), Table 2 and Table 3.

TABLE 1
COMMON PARAMETERS AND THEIR VALUES

Parameter	Value
Signal to Interference Ratio (SIR)	6
Channel Bandwidth (Bw)	2 MHz
Thermal + Receiver Noise	-169 dBm / Hz
Packet Reception Threshold	-94 dBm
Interference Threshold	-108 dBm
Frequency (f)	2.4 GHz
K	$9.8946 * 10^{-05}$

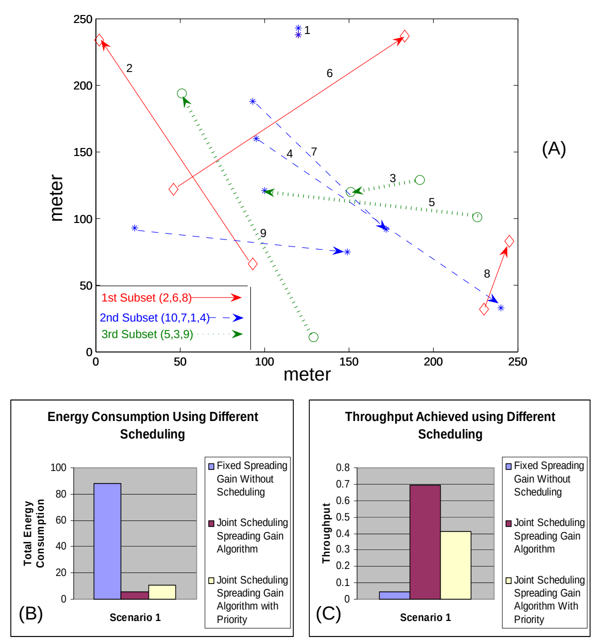

Fig. 3. (A)Network Scenario, (B)Total Energy Consumption and (C)Throughput Using Different Scheduling

For the simulation of Joint Scheduling-Spreading Gain Algorithm With Priority , priority = [0; 0; 0; 0; 1; 0; 0; 0; 0;

0] is assigned to node 1 to node 10 respectively. Assignment of these priority assumes that node 5 was eliminated from transmission earlier and thus why its priority has increased to 1. Point to be noted that this assumption is only for one scenario as an example. In all other simulation we considered random priority to verify our algorithm.

The network scenario used to illustrate the potential of our proposed algorithm is shown in Figure 3(A).

TABLE 2
ENERGY CONSUMPTION AND THROUGHPUT OF THE NETWORK

Observations	Fixed Spreading Gain Without Scheduling	Joint Scheduling-Spreading Gain Algorithm			Joint Scheduling-Spreading Gain Algorithm With Priority		
	1 Time Slot	1/3 Time Slot	1/3 Time Slot	1/3 Time Slot	1 Time Slot	1 Time Slot	1 Time Slot
		Subset 1	Subset 2	Subset 3			
Nodes * To Transmit	1,2,3,4,5,6,7,8,9,10	2,6,8	10,7,1,4	5,3,9	2,5,6	8,9,1	3,10,7,4
Energy Consumption	88.0782	1.8504	2.4090	1.4217	6.8293	0.1989	3.4980
Total Energy Consumption	88.0782	5.6810			10.5261		
Throughput	0.0431	0.696			0.4137		

* Node numbers are as shown in Figure 2 (A)

TABLE 3
SPREADING GAIN AND TRANSMISSION POWER FOR EACH NODE

Node No.	Fixed Spreading Gain Without Scheduling		Joint Scheduling-Spreading Gain Algorithm		Joint Scheduling-Spreading Gain Algorithm With Priority	
	Spreading Gain	Transmission Power	Spreading Gain	Transmission Power	Spreading Gain	Transmission Power
1	232	0.00001	17	0.0001	3	0.0001
2		0.0469	13	0.0803	37	0.0553
3		0.0033	13	0.0082	25	0.0069
4		0.0935	17	0.0536	25	0.0513
5		0.0466	13	0.0435	37	0.0785
6		0.0410	13	0.0550	37	0.0508
7		0.0283	17	0.0416	25	0.0417
8		0.0068	13	0.0070	3	0.0135
9		0.0814	13	0.0576	3	0.0528
10		0.0318	17	0.0464	25	0.0400

Throughout all simulations spreading gain is considered to be $<= 64$. We didn't put any upper limit to transmission power, as optimisation problem itself takes care of it. Priority for node 5 is kept to 1 and all other nodes priority to Zero for the simulation of Joint Scheduling-Spreading Gain Algorithm With Priority, where we considered node 5 was eliminated from transmission in last time slot. Mobility, addition and deletion of node was not considered in the simulation, as to compare the scheduling among same number of nodes using different algorithms.

The simulation results in Table 2 shows the nodes that can transmit at the same time. For Fixed Spreading Gain Without Scheduling all nodes can transmit at the same time in a single time slot with a very high spreading gain and energy consumption. This solution is considered as the basic solution. For the Joint Scheduling-Spreading Gain Algorithm, spreading gain and energy consumption is very less compared to Fixed Spreading Gain Without Scheduling and considered as an optimal solution. Results for Joint Scheduling-Spreading Gain Algorithm With Priority shows that, although, spreading gain and energy consumption is more than the optimal solution but still much better than the basic solution. On the other hand this algorithm has less processing burden compared to the Joint Scheduling-Spreading Gain Algorithm. It gives us suboptimal solution depending on the priority and position of the node. If the priority is same for all nodes Joint Scheduling-Spreading Gain Algorithm is same as Joint Scheduling-Spreading Gain Algorithm With Priority.

VII. Conclusion

In the above simulation study we have assumed a fully connected network, that is single hop network. We looked into dividing nodes into multiple subsets and using TDMA to allocate time slots for each subsets. The results shows that using Joint Scheduling-Spreading Gain Algorithm total network energy consumption can be reduced by a significant amount than the basic scheduling. Joint Scheduling-Spreading Gain Algorithm with priority takes into account node mobility, addition and deletion of nodes within the network by means of some increase in total network energy consumption in comparison with Joint Scheduling-Spreading Gain Algorithm. We plan to extend this work to multihop network with different spreading gain allocated to different transmitter receiver pair in the near future.

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