"CSMA-Based and Optimal link scheduling in Multihop MIMO Networks using SINR Model "

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Abstract – The development of high-performance distributed scheduling algorithms for multi-hop wireless networks have become a matter of interest in recent years. The problem is challenging when studied under a physical interference model because it requires the SINR to be above a certain threshold at the receiver for decoding success. Under this SINR model, the transmission failure can be caused by interference due to simultaneous transmissions from far away nodes, which intensifies the difficulty in developing a distributed algorithm for link scheduling. In this paper, we are going to propose scheduling algorithm that uses carrier sensing and show that the algorithm is applicable to distributed implementation as well as it results in throughput optimality. This algorithm has a feature called the dual-state approach. It separates the transmission schedules from the system state means control state ans data state are separated hence can be shown to improve delay performance.

Keywords- *MIMO, CSMA,SINR, Scheduling algorithm, DTMC.*

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I. INTRODUCTION

It is widely accepted that link scheduling (or media access control) is the bottleneck in throughput performance in wireless multi-hop networks. Over many years of research, many scheduling algorithms are implemented to achieve high throughput performance with low interference and complexity. Scheduling in wireless multi-hop networks refers to link activity is coordinated that is packet transmission at a given moment so as to achieve high throughput, fairness, low delay. In wireless networking environments, simultaneous links activations interfere with each other, which a major challenge in developing efficient scheduling schemes. The practical implementation of wireless multi hop networks requires that a scheduling algorithm should be performed in a distributed fashion, which makes the scheduling problem more challenging. Wireless networks exhibit unique characteristics that the signal sent out by a wireless terminal will be received by all the terminals which are in its transmission range, and can possibly cause signal interference to some links that are not intended to receive signal. In simple words, the communication channels are shared by the wireless links. Thus, one of the major problems wireless networks are facing is the reduction of capacity because of interference caused due to simultaneous transmissions. Using multiple channels and multiple links can improve but cannot eliminate the interference. To achieve collision-free communication, we hereby have two alternatives:

One method is to utilize a random access MAC layer scheme. The other is to carefully construct a transmission schedule. In [8, 9, 10, 11] the large scale deployment of IEEE 802.11, Carrier Sensing Multiple Access/Collision Avoidance (CSMA/CA) based scheduling algorithms have been developed and shown to achieve optimal throughput while retaining the key CSMA/CA feature CSMA networks. In particular, the Q-CSMA scheme [10] takes a discrete time approach that is similar to the CSMA time-slotted protocol and can be modeled as a Discrete Time Markov Chain (DTMC) with the product form stationary distribution. It determines a transmission schedule at present by combining active links in the previous time slot and a set of potential candidate links which are willing to participate in scheduling that satisfy the interference condition in a probabilistic manner. This probability is an increasing function of packet queue length. Hence a link with a longer queue will have higher probability to transmit its packet. Even though CSMA can achieve optimal throughput, its delay performance seems to be poor, especially under heavy load. All of the above scheduling schemes are developed on the basis of theoretical graph-based interference models. In a graph-based model, it has a binary interference relation for each and every pair of links. That is, active status of two links simultaneously does not depend on the activity of other links. The graph-based model approximates the signal-to-interference-noise-ratio (SINR) by simplifying wireless interference. However, in practice, the interference constraints are more complex due to the accumulating property of interfering signals.

In [12],D. Qian et al. have taken into of Multi-Input Multi-Output (MIMO) links. For taking practical interference account the combined interference constraints into consideration, we are going to employ the more realistic SINR model. A wireless network is modeled by a graph of 5 links If there is a link between two nodes, that means that if a node transmits a packet with a fixed transmission power P, the note can successfully receive the packet only if there are no other senders at the same time. But since, we seek to activate as many links as possible at the same time. Received signals from other senders will affect the success of the transmission because of the interference. Means that the transmission of a packet over a link is successful only when the SINR of the received signal is more than the SINR threshold. We assume her that a single SINR threshold is used for all the links, which is carefully chosen considering the network density, e.g.,[13]. All links are assumed to have unit capacity (i.e., a packet can be transmitted at a unit time) and Considering time slotted system with a single frequency channel, here each time slot consists of a control slot and a data slot. Each control slot is used to generate a feasible transmission schedule which is to be transmitted during the data slot and has further been divided into control mini slots. That is, a link schedule generated in the control slot is used for transmitting data packets during the data slot.

II. DISTRIBUTED SINR-BASED SCHEDULING ALGORITHM (DSS)

We propose a distributed scheduling algorithm which operates in a CSMA network. Here we will determine the set of simultaneously active links considering the SINR interference model.We will find set of conflicting and non-conflicting links for each link. That is to find *Na*(*li*) and *Nb*(*li*) for every virtual link *li*.

A . Selection of decision schedule

1) Virtual link li who wants to send the data selects a random back-off time uniformly in [1, T], and begins back-off timer.
2) Virtual link *li* stops the back-off timer under one of the following two conditions
(I) *li* hears an INTENT message from virtual link *kj* , and link *li* and *kj* are conflicting links
(II) other virtual links in *V*(*l*) send INTENT messages.
(III|)When *li* finishes the backoff, it sends INTENT message to announce that is has intention to be included in the decision schedule.
4) If there exists a collision among the INTENT messages of different links, *li* will not be included in decision schedule in this control slot.

B. Distributed scheduling algorithm under SINR model

For a given time slot t, we will find a new transmission schedule x(t) by combining the previous transmission schedule x(t − 1) at previous slot (t – 1) and decision vector m(t) at slot t. The decision vector denotes the set of randomly selected links that can be simultaneously activated with the links in x(t−1) without any SINR constraint violation. That is, m(t) ∪ x(t−1) is a feasible transmission schedule. For each link belonging to m(t) ∪ x(t−1), the proposed algorithm will decide whether it can be actually activated or not at data slot by a certain activation probability. In this way, x(t) can be determined by probabilistically selecting links from m(t) ∪ x(t − 1).One thing can be noted here that the state of the links in m(t) and x(t − 1) are changed depending on probability only. All the other links in m(t) ∪ x(t -1) maintain the same state from the previous slot $x_i(t) = x_i(t-1)$. Here assumption is that before starting the scheduling, each node stores received signal strength for other sender node by letting each node broadcast in turn and having the other nodes measure received signal strength as in [15].Using this technique, we can assume that each receiver node of a link can store received signal strength for each sender. Now we will explain how to generate such a decision schedule in a distributed manner using the SINR interference model, which is one of the main contributions of this paper and is detailed in the following. We will first divide a control slot into M control mini-slots. Here each mini-slot consists of two phases. Note that the active links in the previous slot (t – 1) i.e. x(t − 1) are not included in m(t) because they are already eligible links for activation probabilistically at slot t. The candidate links for decision schedule m(t) should satisfy two constraints:

(a) They should be the inactive links at time t−1
(b) They can be active without making the links in x(t − 1) violate the SINR threshold.

Thus, at time each slot t, a candidate link for decision schedule that is m(t) checks whether it has a packet to send, and if so, it will pick a random backoff counter in [0, M-1]. The control slots are used for the backoff process to select the links for m(t). Each sender of a candidate link will decrease its backoff counter by one at each mini-slot. Suppose that the backoff timer of a particular sender of a candidate link, consider S_1, expires at mini-slot m (of slot t) while the nodes that is senders of other links are still in process of decrementing their timers. Then S_1 will broadcast a small control signal which contains the corresponding receiver (say Rc1) information during the first phase of mini-slot m1. If Rc1 successfully receives the control packet, there will be no action in the second phase. Then S_1 judges that its link is included in decision schedule. The other nodes that receive the control packet will only add the received signal power to its total interference power level. One thing to note is that even if a node cannot decode a packet being located outside the transmission range, it can measure its received signal power. Now assume that sometime later the backoff counter of the second sender, consider S_2, expires at mini-slot m_2 and S_2 broadcasts a control packet during the first phase of mini slot m_2. Assume that its corresponding receiver Rc_2 receives the packet successfully but its calculated SINR is less than the SINR threshold. It will then broadcast a busy tone in the second phase of control slot that is at mini-slot m_2. When sender S_2 will receive this busy tone, it will conclude that its link cannot be activated at slot t. So the link with sender is S_2 cannot be included in decision schedule m (t). Note that in this case, received signal power will not be added by other nodes to their interference power since the link is not scheduled in the decision schedule. In this way, the links for m(t) satisfying the SINR constraint are added one by one during the control slot. Note that the receiver that is intention to send data of a control packet checks the SINR requirement as well as the receivers in m(t) till time and in x(t-1) will check whether their received signal strength can still meet the SINR threshold when the link of the control packet is activated. If any of the receptions do not meet the SINR constraint because of the new link that wins the backoff counter, then the interfered receiver will send a busy tone signal, it will indicate that the new link must drop its attempt to join decision schedule m(t). There is one more concern that we need to consider. Due to random backoff timer of each link, there can be a collision among the senders of the links that wish to join decision schedule. In this case, the intended receiver is not able to decode the packet successfully and even if they do not satisfy the SINR threshold, it is not able to send a busy tone. In this case, any node that detects the collision it means if the measured signal is strong but not decodable will send the busy tone. Then the links whose senders cause the collision during control slot will not be included in decision schedule. By following above process flow, a new link will only be added to m(t) as long as it does not interfere with the existing links in m(t) and in x(t−1). After the control slot is over, we will obtain the final schedule m(t) for slot t. Let d(t) = m(t) ∪ x(t−1), which is a feasible schedule for transmission. With the schedule d(t), we determine the transmission schedule x(t) as $x_i(t) = d_i(t)$ with probability pi and 0 with probability $1 – p_i$ (2) where $d_i(t)$ is 1 if link i is included in d(t). Each link in decision schedule is activated with a link activation probability p_i depending on the queue length. Finally,in the data slot of slot t, the links in x(t) will transmit data packets.

III. SINR MODEL VERSUS PROTOCOL MODEL

In MIMO networks, two links can coexist with each other if they are able to transmit simultaneously without affected by interference. An interference model specifies the link coexistence constraint only i.e. which links are to be simultaneously activated. In contrast, under SINR model, the success rate of transmission not only depends on its own channel condition but also on the level of the co-channel interference. A transmission of a link is considered to be successful if it has SINR greater than a threshold value determined previously. Hence the SINR model has ability to capture the probabilistic nature of wireless MIMO multihop communications which is not the case with protocol or matching based models. The SINR model which is built upon recent advances in PHY-layer communication research has opened a new path for more efficient resource utilization and allocation in wireless networks. Consider that transmission power is equally split among all the transmit antennas. As there is no interference information available at the transmitter antenna, transmission rate of each stream is set to be the same, denoted by Rs. Our perception is that the rates for data streams depend on the SINR values that means eventually on interference, which is unknown and time-varying. So it is more practical to set the same rate for different streams.

IV. CONCLUSION

We explored CSMA-based Multiple input Multiple Output pipe scheduling in both discrete-time system and continuous-time system considering SINR ratio. Hence can conclude that algorithms that are based on the protocol interference model have low computational complexity and are simple to implement, but yield low network throughput. However, algorithms based on SINR graph representation have are computationally complex but and are more cumbersome for implementation, but achieve higher network throughput. A link scheduling algorithm in wireless multi-hop networks has been a critical problem since the links in multi-hop networks can be activated simultaneously is the key performance bottleneck. However, previous scheduling algorithms have considered only graph-based interference models. In this paper, we propose a scheduling algorithm Distributed scheduling that takes into account a SINR-based interference model. DSS operates in the distributed fashion and achieves throughput optimality. The main characteristic of DSS is the dual state approach, in which more links have been activated compared to other CSMA scheduling algorithms while maintaining the throughput optimality. Simulation is carried out to reveal that DSS shows the lower delay performance than other scheduling algorithms. We believe that our work can find applications in some time slotted wireless networks, *e.g.*, time slotted wireless sensor networks or wireless mesh networks. Knowing these factors that determine the throughput of a network also helps to better deploy a multihop wireless network and enhance the overall throughput performance.

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