Quadrant Based DIR in CWin Adaptation Mechanism for Multihop Wireless Network

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ABSTRACT

In Multihop Wireless Networks, traffic forwarding capability of each node varies according to its level of contention. Each node can yield its channel access opportunity to its neighboring nodes, so that all the nodes can evenly share the channel and have similar forwarding capability. In this manner the wireless channel is utilized effectively, which is achieved using Contention Window Adaptation Mechanism (CWAM). This mechanism achieves a higher end-to-end throughput but consumes the network power to a higher level. So, a newly proposed algorithm Quadrant-Based Directional Routing Protocol (Q-DIR) is implemented as a cross-layer with CWAM, to reduce the total network power consumption through limited flooding and also reduce the routing overheads, which eventually increases overall network throughput. This algorithm limits the broadcast region to a quadrant where the source node and the destination nodes are located. Implementation of the algorithm is done in Linux based NS-2 simulator.

Keywords

Multihop wireless network, CSMA/CA, Routing protocol, restricted flooding.

1. INTRODUCTION

Multihop wireless networks (MWN) are recently been used in a wide civilian use and military applications. Main advantage is no need for pre-existing infrastructure. MWN consist of a number of either stationary or mobile wireless stations, which serve as relays forwarding traffic from other nodes and provide wide network connectivity. The main task is to maintain the network throughput that depends on the achievable channel capacity at each link and power consumption that depends on the type of routing metrics used in the network. In order to improve the end-to-end throughput performance of IEEE 802.11 DCF, CWA mechanism [1] is used which adaptively varies the size of the Contention Window (CW) depending on the traffic generated. The basic access mechanism of the IEEE 802.11 DCF is carrier sense multiple access with collision avoidance (CSMA/CA). The idea is to prevent collisions at the moment they are most likely to occur, i.e. when the bus is released. All source nodes are forced to wait for a random number of timeslots and then sense the medium again, before starting a transmission. If the medium is sensed to be busy, the source node freezes its timer until it becomes free again. Thus, the chance of two source node starting to send simultaneously is reduced. The main drawback of this mechanism is that it utilizes the entire network and hence, power consumption is higher. So, to fulfill the objective and to overcome the drawback, a cross layer between the network layer routing protocol and the data link layer are done. That is restricted flooding algorithm called Q-
DIR [2] is cross layered with the CWA mechanism. Various routing metrics usually used are shortest path, link stability and minimum number of hops towards the destination. Routing protocols can be categorized into topology-based [3] and position-based protocols [4]. In the former, on-demand or proactive flooding of route request (RREQ) are broadcast at each node to all neighbours to detect routes. In position-based protocol, routing is optimized by making use of location information through beaconing available at each node.

Position-based protocols are further categorized into greedy forwarding and restricted flooding [4]. In greedy forwarding [5], based on location information of the destination node, source node will select the node with the best progress towards the destination. The location information of the destination will then be inserted in their data packet and unicast to the selected node. Upon receiving the data packet, the selected node will then select the best node among its neighbours and the process continues until the data packet reaches the destination. As the name implies, in restricted flooding, nodes that are located nearer to the destination or in a forwarding zone, will broadcast the packet. Distance and forwarding zone information are computed at the respective nodes to determine their progress towards destination. These nodes will then broadcast the packet and the process is repeated at each intermediate node until it reaches the destination.

2. PROBLEM STATEMENT

The nodes in the MWN that are with different traffic forwarding capability contend with each other which has the same $C_{\text{Wmin}}$ value. The node with the largest forwarding capability may utilize the wireless medium aggressively and eventually causes the decrease in the end-to-end throughput of the multihop path. Thus, the algorithm needs to differentiate the channel access probability of each node by adjusting the CW size depending on the traffic forwarding capability. This implies that none of the relay nodes forwards excessive packets to its corresponding receiver. In summary, by differentiating the contention window size at each node, all the other nodes except the source are able to increase the traffic forwarding capability, which results in a significant increase in the end-to-end throughput.

In order to improve the throughput of MWN the following issues must be considered:

(i) How to estimate the traffic forwarding capability at each node;
(ii) How to differentiate the contention window size depending on the traffic forwarding capacity;
(iii) How to increase the end-to-end throughput by regulating the throughput of traffic relayed at each hop in distributed and scalable manner.

As a result end-to-end throughput can be increased but CWA mechanism utilizes the entire available network nodes to broadcast the data to the destination. CWAM uses greedy forwarding technique, where the request is given to all the neighbouring nodes to establish the path. Eventually this consumes more power. Since the network is a stand-alone device this operates on batteries.
Thus, for reducing the power consumption, the path in which the broadcast occurs must be limited to a quadrant. Instead of utilizing all the nodes in the network, only the nodes in the broadcast region have to involve in transmission. The mathematical computation of the location information in the kernel environment will incur further processing delay in the current node [6]. Hence, the delay needs to be reduced by inserting the location information of the source node or the previous intermediate node in the data packet, and so, periodic beaconing will be eliminated.

3. RELATED WORK

Related work falls into two broad categories: Tuning of back-off parameters and restricted flooding.

3.1. Tuning of Back-off Parameters

In IEEE 802.11 DCF, the back-off parameters such as $CW_{\text{min}}$ and $CW_{\text{max}}$ are fixed. To analyse the impact of the back-off parameters on network performance, Bianchi [8] derived a two dimensional Markov chain model for the exponential backoff process. Using this model, it was shown that the number of stations and the minimum CW size have significant impacts on the overall performance of IEEE 802.11 DCF. Bianchi and Tinnirello [9] proposed how to estimate the number of active stations using an extended Kalman filter in a WLAN. Tuning of the MAC parameters can effectively improve the network performance when the number of active stations is properly estimated. Cali [10] proposed a distributed algorithm called IEEE 802.11+, which enables each node to estimate the number of contending nodes at any given time. They also derived an analytical model which gives a theoretical maximum bound on the network capacity, and tried to find the optimal CW value to achieve the theoretical throughput limit. Kwon [11] proposed a Fast Collision Recovery (FCR) protocol, which is a contention-based protocol that redistributes the back-off timer among all competing stations with an objective of reducing the idle back-off time.

3.2. Restricted Flooding

Distance from the node to the destination is used to determine the nodes participation in the route discovery process. Nodes that are further away from source will not participate. Relative Neighbourhood Graph (RNG) [12], which together with local information of distance to neighbours and distances between neighbours will minimize the total energy consumption.
AODV protocol uses a reactive type of routing which utilizes maximum power at initial stage of transmission. Location-based Geocasting and Forwarding (LGF) [13], calculates distances to all nodes in the network and will compare the distance information of the source to the destination extracted from the request packet to determine its participation. Angle Routing Protocol (ARP) [14] uses the angle made from the straight line drawn from source to destination as the restricted region whereby all nodes in this region will participate in the route discovery. However, DDB [15] uses the location information of the destination node and also of the intermediate node which are inserted in the request packet. With this additional information, an intermediate node can calculate the estimated additional covered area that it would cover with its transmission which is based on Dynamic Forwarding Delay (DFD). The concept of DFD is to determine when to forward the packet and node with more area covered will be given a smaller delay to broadcast and hence, will broadcast first. All the above protocols require computation of the distance and angle at all intermediate nodes to determine the nodes that are located in the forwarding region.

4. CROSS LAYER FRAMEWORK

A cross layer is made between the data link layer and the network layer of the OSI model to improve the performance of IEEE 802.11 DCF.

4.1. CWA Algorithm

In the CWA mechanism, the traffic forwarding capability \( \alpha_i \) is defined as the ratio of the rate of incoming and outgoing traffic at a node \( i \):

\[
\alpha_i = \frac{i^{out}}{i^{in}} \quad (1)
\]

where, \( i^{out} \) - outgoing traffic at a node \( i \)
\( i^{in} \) - incoming traffic at a node \( i \)

If a node can forward all the received packets to its neighboring node without packet loss, then \( \alpha_i \) is equal to one. On the other hand, if node receives a large number of packets but cannot forward them at the same rate as it receives, and then \( \alpha_i \) is less than one. If node has the smallest forwarding capability \( \alpha_i \) among the nodes on the multihop path, it may be a bottleneck relay node of the path.

Contention window adaptation algorithm has the following step which is implemented across the network.

Algorithm 1:

1. InPkts: the number of all the incoming packets at particular time \( T \)
2. DstPkts: the number of outgoing packets whose destination is itself.
3. \( i^{in} = \text{InPkts} - \text{DstPkts} \)
4. OutPkts: the number of all the outgoing packets for \( T \)
5. SrcPkts: the number of incoming packets whose source is itself.
Fig. 2 Steps in CWA Algorithm

Fig. 2 gives the steps involved in the CWA mechanism. Here, ‘inpks’ denotes the incoming data packets, ‘dstpkts’ denotes packets at the destination, and ‘outpkts’ denotes the outgoing data packets and ‘srcpkts’ denotes the packets at the source. On the line 7 in Algorithm 1, an upper bound is placed on the rate of outgoing traffic. Even though there are no incoming packets, the packets accumulated in the buffer can be transmitted. For a short time interval, the outgoing rate could be higher than the incoming rate depending on the buffer size, and it may lead to a false decision in updating CWmin in line 8. This is the reason that we limit the rate estimate of outgoing traffic up to that of incoming traffic.

Third, if the traffic load is sufficiently low and does not incur any packet loss, CWmin has the tendency to be large with the use of the adaptation rule. For simulations and experiment, minth and maxth of CWmin are set to 1 and 32, respectively. We set maxth of CWmin to 32 and set minth of CWmin to 1.

4.2. Q-DIR algorithm

Q-DIR is a restricted routing protocol that concentrates on a specified zone using location information provided by a location service as in fig. 3. In Q-DIR operation, the location information of the source and destination nodes is piggy-backed in the route request (RREQ) packet and then broadcasted.

Fig. 3 Less participating nodes in Q-DIR algorithm
Upon receiving the RREQ, intermediate nodes will compare using a simple mathematical comparison based on the coordinates of source, destination and the current node that directs the packet towards the destination as in Fig. 4. This mathematical processing is done in the kernel environment to reduce the routing overhead.

Algorithm 2:

1. Divide the network area into four quadrants with source as origin
2. Quadrant of intermediate node compared to source node.
3. Quadrant of destination node compared to source node.
4. If they lie in same quadrant, then forward the data packets. Else drop the packets.

Fig. 4 Steps in Q-DIR algorithm

The decision to participate is in reactive manner. Once the decision to broadcast has been made, the intermediate node will insert its location by replacing the source node coordinates and append its address and sequence number at the end of the RREQ packet. It will then broadcast the packet. The process will be repeated at each intermediate node until it reaches the destination. The replacement of the source node location information with the intermediate node coordinates will make the packet more directed towards the destination since the comparison now is based on the previous node. Upon receiving the RREQ, destination node will send a route reply message (RREP) back to source via the path taken to reach the destination that was appended in the RREQ as it traverses across the network. There is no need for the route discovery to the source node.

4.3. Cross Layer Design

The network has the wide spread of nodes, where there may be many source nodes and destination nodes involved in data transmission. This transmission is done via various intermediate nodes. First step is to divide the broadcast region into four quadrants by keeping source as the origin. Secondly, location of the destination in noted and broadcast region is limited to that particular quadrant and is achieved using Q-DIR algorithm. Only the intermediate nodes in that quadrant will be selected according to the algorithm 2 and remaining nodes will be rejected. Similarly for all the source nodes same procedure is done. Third step is to apply CWA mechanism to each of the nodes involved in broadcasting of data packets. This adaptively varies the CW size depending on the incoming traffic. CWA mechanism is implemented in all the forwarding nodes to avoid collision and packet drop.

The general procedure involved in the cross layer design between Q-DIR and CWA is listed in the fig. 5.
1: Place the nodes in a grid topology
2: Identify the source and destination node
3: With source as origin, divide the network into four quadrant
4: Select the quadrant in which the destination node is present
5: Apply the Algorithm 2 to the selected quadrant
6: After estimating broadcast route, apply Algorithm 1 to each forwarding node.

Fig. 5 Cross Layer Design Procedure

Q-DIR in network layer is used for routing which reduces the delay while transmission and CWA mechanism in data link layer is used to adaptively vary the CW size and so it achieves a maximum throughput. As shown in Fig.6, a cross layer between CWA mechanism of Data link layer and Q-DIR of Network layer is implemented to enhance performance of IEEE 802.11 DCF.

5. SIMULATION RESULTS

Simulation of Q-DIR with CWAM is done in Network Simulator-2 (ns-2). Comparison is done between the total flooding protocol (AODV) and restricted flooding protocol (Q-DIR with CWAM). A network model of 49 nodes that forms a 7 by 7 grid model where the distance from adjacent nodes are 30m. Based on this grid model, the density is 1 node per 661m² and the data rate is 2 Mbps. Simulation configuration parameters are given in the table I.
TABLE I SIMULATION CONFIGURATION PARAMETERS

| Configuration Parameters                  | Value   |
|-------------------------------------------|---------|
| Max. No. Of hops between two nodes        | 10      |
| Average one hop traversal time            | 60 ms   |
| Route discovery time                      | 5000 ms |
| Route delete time                         | 25000 ms|
| Number of RREQ tries                     | 3       |
| Total traversal time                      | 1200 ms |

Various performance comparisons are made between the normal operation of the network under normal AODV and the operation using the newly proposed algorithm that is cross layer of Q-DIR with CWA mechanism.

Fig. 7 Aggregate Throughput comparison

Aggregate throughput comparison is done between AODV and QDIR-CWA. In fig. 7, the throughput achieved by QDIR-CWA is higher compared to the AODV. This is because CWA mechanism adaptively adjusts the CW size depending on each node’s incoming traffic.

Fig. 8 Delay comparison

In the figure 8, delay obtained using QDIR-CWA mechanism is lower than that is obtained from normal AODV. The reason is that QDIR eliminates the periodic beaconing and hence reduces the routing overheads while transmission. So, delay is reduced in QDIR-CWA mechanism.
Fig. 9 Packet Delivery Ratio

In the fig. 9, CWA mechanism achieves a higher delivery ratio because this algorithm aims to avoid collision and packet drop. Hence, the data packets from the source are properly delivered to the destination and achieve a higher packet delivery ratio than AODV.

Fig. 10 Energy Consumption comparison

In fig. 10, energy consumed by network using AODV protocol is higher than the energy consumed by the network using QDIR-CWA. Since, QDIR-CWA restricts the broadcast region to a particular zone; usage of energy by the remaining area is avoided. Hence, QDIR-CWA consumes less energy which results in less power consumption.

Fig. 11 Routing Overhead comparison
Fig. 11 shows that AODV exhibits more routing overheads because of the reason that it is a reactive type of routing. The request to the nodes in the network is given prior to transmission. QDIR-CWA has a simple route calculation and the elimination of the periodic beaconing reduces the routing overhead. Thus, from all the above factors it is known that QDIR-CWA mechanism achieves better performance compared to AODV.

6. CONCLUSION

The Cross layer between the Q-DIR algorithm and CWA mechanism increases the overall network performance. Q-DIR algorithm uses the location information of the source, destination and the intermediate node to select the broadcast region. Nodes in the particular broadcast region only will broadcast while other nodes will ignore the RREQ packet. CWA mechanism is applied to each of the nodes in the broadcast region. CWA mechanism reduces the packet drop due to collision, which improves the throughput and Q-DIR reduces the mathematical computation complexity by eliminating the periodic beaconing. This achieves reduced delay and reduced overhead. As a result, the overall network end-to-end throughput is achieved using CWAM whereas reduced routing overheads and reduced power consumption is achieved using Q-DIR. Therefore, the cross layer of Q-DIR and CWAM provides an increased network performance.

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