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ABSTRACT

Mobile ad hoc networks (MANETs) are becoming more common technology in wireless network because of its characteristics highly dynamic, autonomous topology and multi-hop relaying and typical network loads considered for MANETs are increasing as applications evolve. The traffic load may be highly non- uniform over the network area due to the dynamic behavior in MANETs. A lightweight dynamic channel allocation mechanism and a cooperative load balancing strategy are applied in cluster based MANETs to handle non uniform traffic load by efficiently use the resources such as bandwidth and energy. The protocols that determine the behavior of the network should dynamically adapt to the changing conditions. A novel coordinate MAC protocol called CDCA TRACE protocol is designed to utilize these mechanisms to improve performance in terms of throughput, energy consumption, inter-packet delay variation (IPDV). The carrier sensing mechanism (CSMA) enables CDCA-TRACE protocol to select the channel coordinator more effectively to obtain less energy consumption and inter packet delay variation. The improved bandwidth efficiency under non uniform load distribution is verified by comparing it with the protocols like IEEE 802.15.4 protocol with GTS mechanism and 802.11uncoordinate protocols.

Keywords— Mobile ad hoc networks, CDCA-TRACE, carrier sensing.

1. INTRODUCTION

MOBILE ad hoc networks have been an essential class of networks, providing communication support in mission critical basic situations including battle-field and tactical missions, search and rescue operations, and disaster relief operations. Group communications has been fundamental for many applications in MANETs. The typical number of clients of MANETs has persistently expanded, and the applications supported by these networks have become increasingly resource intensive. This, in turn, has increased the importance of bandwidth efficiency in MANETs. It is crucial for the medium access control (MAC) protocol of a MANET to adjust to the dynamic environment as well to efficiently manage bandwidth utilization.

Based on the collaboration level MAC protocols for wireless networks can be classified as coordinated and uncoordinated [4]. Uncoordinated protocols such as IEEE 802:11 are applicable only for low network loads. In Coordinated MAC protocol such as IEEE 802.15.3 [8], IEEE 802.15.4 [9], and MH-TRACE [7], the channel access is regulated and the channel controllers determine how the channel is shared and accessed. Coordinated channel access scheme provide support for quality of service (QoS), reduce energy dissipation, and increase throughput for dense networks.

Some of the key challenges in effective MAC protocol design are the augmentation of spatial reuse and providing support for non-uniform load distributions as well as supporting multicasting at the link layer. The dynamic behavior in MANETs, the traffic load may be highly non-uniform over the network area. So coordinated protocols require careful design at the MAC layer, allowing the channel controllers to utilize spatial reuse and adapt to any changes in the traffic distribution. Thus, coordinated

MANET MAC protocols need specialized spatial reuse and channel borrowing mechanisms that address the unique characteristics of MANETs in order to provide as high bandwidth efficiency. In this paper we propose two algorithms to adapt to the non-uniform load distributions in MANETs:

- A light weight distributed dynamic channel allocation (DCA) algorithm based on spectrum sensing, and
- A cooperative load balancing algorithm in which nodes select their channel access providers based on the accessibility of the resources.

We apply these two algorithms into MH-TRACE, an energy efficient real-time coordinated MAC protocol [7]. Although MH-TRACE includes spatial reuse, it does not provide any channel borrowing or load balancing mechanisms and thus does not provide ideal support to non-uniform loads. Hence, we create the new novel protocols of DCA-TRACE, CMH-TRACE and the combined CDCA-TRACE by using MH-TRACE.

2. MH-TRACE PROTOCOL

In MH-TRACE, certain nodes assume the roles of cluster-heads (CHs). All CHs send out periodic Beacon packets to announce their existence to the nodes in their neighborhood. When a node does not receive a Beacon packet in a predefined measure of time, it assumes the role of a CH. This scheme ensures the existence of at least one CH around every node in the network. In this, time is divided into superframes of equal length as shown in Fig. 1, and further divided into frames. Each clusterhead operates using one of the frames in the superframe structure and provides channel access for the nodes in its communication range.

Each frame in the superframe is further divided into sub-frames. In the Beacon slot, CHs announce their presence and the number of available data slots in the current frame. The CA slot is used for interference estimation for CHs operating in the same frame (co-frame CHs) and CHs transmit a message with a given probability and listen to the medium to calculate interference caused by other CHs operating in the same frame.

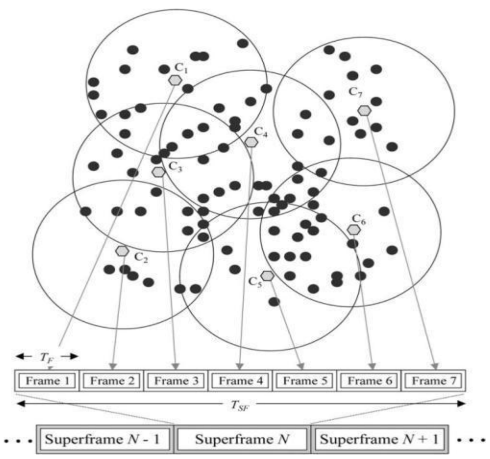

Fig.1 Structure of MH-TRACE protocol

By monitoring the interference levels in the medium during the Beacon and CA slots of each frame, CHs switch to the least noisy frame from their perspective.

Contention slots are utilized by the nodes to send their channel access requests to the CH. A node that wants to access the channel randomly selects a contention slot and transmits a contention message in that slot. After listening to the medium during the contention slots, the CH becomes aware of the nodes that have channel requests and forms the transmission schedule by assigning available data slots to the nodes. After that, the CH sends a Header message that includes the transmission schedule.

During the IS slots, nodes send short packets summarizing the information that they are going to be sending in the corresponding data slot. By listening the IS packets, receiver nodes become aware of the data that are going to be sent and may choose to sleep during the corresponding data slots. These slots contribute to the energy savings mechanism by letting nodes sleep during the relatively longer data slots whose corresponding IS packets cannot be decoded. IS packets can also carry routing information. In this paper, the performance of MAC layer alone is investigated so we assume that all the nodes that can successfully receive the IS packet listen to the corresponding data slot.

Another use for the IS packets is to notify the CH about the utilization of the slot by the assigned node. CHs automatically reserve a data slots for nodes that had a reservation in the previous superframe and actively used it. CHs drop the reservation in the case of either missing IS packets or an IS packet with an end-of-stream instruction. In the beginning of its frame, each CH calculates the available data slots and includes this information in its Beacon packet. We utilize this information in both the dynamic channel allocation and the cooperative load balancing algorithms.

3. OVERVIEW OF CDCA-TRACE FRAMEWORK

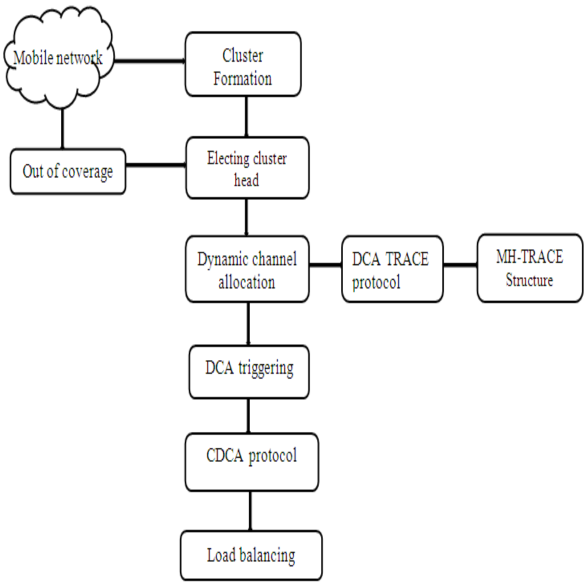

Fig.2 CDCA-TRACE Framework

Fig.2 shows the overview of CDCA-TRACE protocol which performs dynamic channel allocation and cooperative load balancing. This framework use MH-TRACE Structure to design DCA-TRACE protocol for dynamic channel allocation and CDCA-TRACE for cooperative load balancing by probabilistically triggering the DCA-TRACE. The Dynamic channel allocation and cooperative load balancing scheme is explained in following section.

4. DYNAMIC CHANNEL ALLOCATION (DCA)

In DCA-TRACE, if the cluster is overloaded, CHs operate in more than one frame per superframe. And based on the load level, CHs decide on the number of frames they require and opportunistically choose that many frames from the least noisy frames. This includes two additional mechanisms on top of MH-TRACE:

- A mechanism to keep track of the interference level from the other CHs in each frame and
- A mechanism to sense the interference level from the transmitting nodes in each data slot in each frame.

These mechanisms make use of existing messages and do not add complexity. The DCA-TRACE measure the interference level from other CHs in their own frame using CA slot and in other frames using Beacon slots through listening to the medium to select the minimum interference frame. In order to accommodate temporary changes in the interference levels that may occur due to CH resignation or unexpected packet drops, an exponential moving average update mechanism is used to determine the current interference levels in each frame. At the end of each frame, the interference level of the Beacon and CA slots are updated with the measured values in that frame using

$$L_{a,b} = \begin{cases} S_{a,b} & if\ L_{a,b-1} < S_{a,b}; \\ (1-\propto)L_{a,b-1} + \propto S_{a,b} & otherwise, \end{cases} \qquad (1)$$

where $L_{a,b}$ and $L_{a,b-1}$ are the interference levels of the ath slot in the current and the previous superframe, respectively. $S_{a,b}$ is the measured interference level of the ath slot in the current superframe, and α is a smoothing factor.

In DCA-TRACE, CHs mark a frame as occupied if there is another cluster that uses the frame and resides closer than a certain threshold, Hg_{intf} measured through the high interference value of that frame. Even under high local demand, CHs cease from accessing these frames that have high interference measurements, in order to protect the stability of the clustering structure and the existing data transmissions. Based on the reservation in the previous frame, CHs determine the number of frames N which they need to access at the end of each superframe . Depending on the interference level of each frame, CH choose the least noisy N frames that have an interference value also below a common threshold, Th_{intf} . If the number of accessible frames is less than N, the CHs operate only in the accessible frames. Th_{intf} prevents excessive interference between co-frame clusters that can conceivably destabilize the clustering structure.

Another mechanism that DCA-TRACE adds on top of MH-TRACE is,

- The dynamic assignment of data slots.

Since DCA-TRACE introduces channel borrowing, the CH must allocate another data slot that has a lower interference value by avoiding reallocating a data slot that has been borrowed by another CH. In order to do this, CHs keep track of the interference levels of each IS slot of each frame in the superframe. The exponential moving average smoothing mechanism of (1) is also used in IS frame to accommodate the temporary changes in cluster. Knowing the interference values of all IS slots, the CH opportunistically assigns the accessible data slots to the nodes that request channel access starting with the slot that has the lowest interference value. This mechanism helps to reduce any conceivable collisions between the transmissions having the same data slot.

5. COLLABORATIVE LOAD BALANCING

DCA-TRACE handles non-uniform load distribution by allowing CH to access more than one frame in the superframe. Same problem can also be handled by member nodes. To add cooperative CH monitoring and reselection on top of MH-TRACE and DCA-TRACE, we propose CMH-TRACE and CDCA-TRACE respectively. In this, nodes continuously monitor the accessible data slots at the CHs around themselves announced by the Beacon messages. When all the accessible data slots for a CH are assigned, with a probability p, the active nodes endeavor to trigger the cooperative load balancing algorithm. When this algorithm is triggered, the node that is currently utilizing a data slot from the heavily loaded CH contends for data slots from other nearby

CHs while keeping and utilizing its reserved data slot until it secures a new data slot from another CH.

The additional contention overhead introduced to neighboring CHs by the cooperative load balancing is limited. It is important to note that only the active nodes that have access to another CH with free resources can trigger cooperative load balancing algorithm. Probabilistically triggering the algorithm further reduces this load.

Cooperative load balancing does not alter the clustering structure, and it is desirable over selecting an additional frame at the CH. However, cooperative balancing does not completely solve the problem. The source nodes may not be in the vicinity of another CH, and hence their load cannot be transferred to another CH. In that case, triggering the DCA algorithm is required. Thus, in CDCA-TRACE, we include the additional frame selection algorithm of DCA-TRACE with some delay. A fully loaded CH resets a counter, R_{DCA}= 0, and starts incrementing it at the beginning of each superframe while it remains fully loaded. The CH attempts to access an additional frame when $R_{DCA>=}$ T_{DCA}. This provides time for the active member nodes to trigger the cooperative load balancing algorithm and transfer their load to nearby CHs.

6. PERFORMANCE EVALUATION

The performance of DCA-TRACE and CDCA-TRACE are compared with protocols like MH-TRACE, IEEE802.11 under Localized Load Distribution and Random Load Distribution networks. The result shows the improved bandwidth efficiency through energy consumption and interpacket delay variation.

A coordinated protocol, CDCA-TRACE keeps the advantages of low energy consumption and very low jitter. The average energy consumption per node per second for all four protocols is presented in Fig. 3. DCA-TRACE consumes only 54 percent of the energy consumed by IEEE 802.11, even though the number of receptions is significantly larger. The 16 percent increase in the average energy consumption in DCA-TRACE compared to MH-TRACE is the result of the increased number of transmissions and receptions.

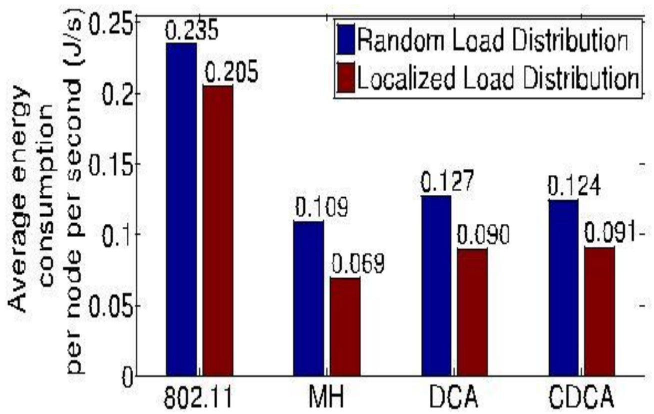

Fig.3 Avg. energy consumption per node per sec of protocol

The average absolute IPDV over all transmitter and receiver pairs is presented in Fig.4. DCA-TRACE leads to a three orders of magnitude smaller average absolute IPDV compared to 802.11because of channel reservation scheme. Compared to MH-TRACE, DCA-TRACE has a larger average absolute IPDV due to the CHs actively monitoring IS slots for minimum interference and changing slot reservations accordingly with changing conditions. However, the tradeoff between minimum interference point of operation and minimum packet delay variation can be resolved according to the requirements of the application by modifying the slot reservation mechanism at the CHs.

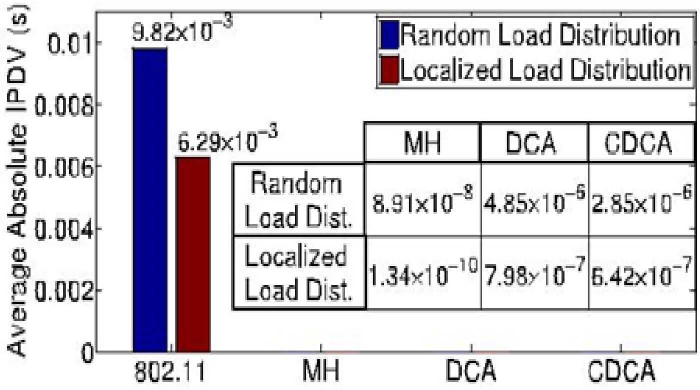

Fig.4 Average absolute interpacket delay variation

To sum up, under heavy and randomly distributed loads, CDCA-TRACE not just expands the number of source nodes that can get channel access compared to an uncoordinated protocol, IEEE 802.11, yet it additionally reduces the number of collisions, average energy consumption, and average absolute IPDV drastically, leading to a higher number of receptions and significant energy savings.

7. CONCLUSION

The non-uniform load distribution in MANET is efficiently handled by CDCA-TRACE protocol by using dynamic channel allocation and cooperative load balancing mechanism. These mechanisms are used for proper channel allocation to improve bandwidth efficiency. The carrier sensing mechanism enables the CDCA-TRACE to select channel coordinator more effectively and obtain the less energy consumption and inter packet delay variation when compared to IEEE 802.15.4 and uncoordinated IEEE 802.11 protocols. These mechanisms are fully utilized on MAC layer capabilities for local broadcasting services.

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