On the Construction of a Collision-Free Schedule of Beacons in a Wireless Multi-Hop Network

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***Abstract*—Organizing multi-hop wireless networks medium access control is a challenge due to the presence of the hidden node problem. It requires reliable coordination among neighbours and second-hop neighbours. In this paper we propose the construction of a collision-free beacon schedule that can be a first step towards the orchestration of effective medium access. The construction process involves iterative trial and error until a collision-free schedule is found. The participating nodes will keep changing the schedule until all the beacons are successfully received. At this point, the nodes simply keep repeating the successful schedule.**

***Index Terms*—Medium Access Control, decentralized constraint satisfaction solver, learning MAC protocol**

I. Introduction

Medium access in multi-hop wireless mesh networks is complicated by the fact that not all the stations are in each other's transmissions range. Therefore is no longer possible to rely on Carrier Sense Multiple Access to coordinate the access to the medium. It is likely that transmissions overlap and interfere with each other. A completely random MAC protocol will not offer satisfactory performance. Some kind of coordination among neighboring nodes is needed.

II. Related Work

[1]

III. IEEE 802.11s Mesh Beacon Collision Avoidance

A Mesh Beacon Collision Avoidance (MBCA) is described in [2]. The solution consists of sometimes delaying the beacon transmission to check for possible overlapping transmissions among the one-hop neighbours. It also involves including information about the timing of beacons in beacons.

This approach has some shortcomings. It does not prevent that two-hop neighbors choose overlapping beacon transmitting instants. The timing information in beacons is available only in case of successful transmission and reception. In the critical case in which collisions occurs and timing information is needed, it is not available. Delaying the beacon sometimes seems also problematic. It is not impossible that the two colliding beacons choose to delay simultaneously and therefore the collision is not detected. If the beacons are not delayed very frequently, it takes a long time to detect the collision. If the beacons are delayed frequently, additional randomness is introduced that can easily result in more collisions.

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IV. Assumptions

We model the network topology as a graph. In the topology graph, the nodes represent wireless stations and the arcs between two nodes mean that those nodes can communicate with each other. If a node has two neighbours transmitting simultaneously, it is assumed that the messages are garbled an lost. A node can only detect and receive the transmissions of its immediate neighbours, and only if there is a single neighbour active.

These are strong assumptions because, in reality, wireless propagation is much more complicated. The carrier sense range exceeds the transmission range and there is capture effect. There are a large number of factors that determine whether a transmission is successful or not. Nevertheless, for tractability, we use the above described graph model.

V. A Beacon Schedule

A recurrent solution in wireless networks is the use of beacons for synchronization and signaling. Beacon messages are very short, which means that the likelihood of collisions is lower. This beacons can be very useful for network coordination and management.

A schedule of beacons defines special times in which beacons can be transmitted. Let us assume that beacons should be transmitted every T_b seconds. Then, it is also necessary to define a schedule length S which is the number of beacons in a schedule. Each station transmits a beacon once in every schedule in one of the S allowed time instants. When the schedule is over, it is repeated again.

A beacon includes a list of all the beacons received by the station in the last schedule. When a station A receives beacons from all its neighbors confirming that they have received the beacon of station A, this station can assume that its beacon has not suffered any collision.

The challenge is to construct a schedule in such a way that all the neighbors of a station can listen to its beacon. When such schedule is successfully constructed, all the nodes will receive confirmation of successful reception of its beacon from all neighboring stations.

VI. The interference graph

From the topology graph we derive the interference graph. There is an arc between two nodes the simultaneous transmission of those two nodes results in interference. Given the interference graph, the problem reduces to map coloring problem.

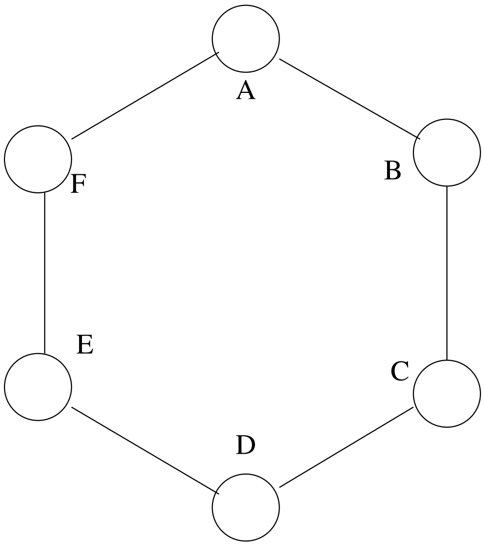

Fig. 1. Topology

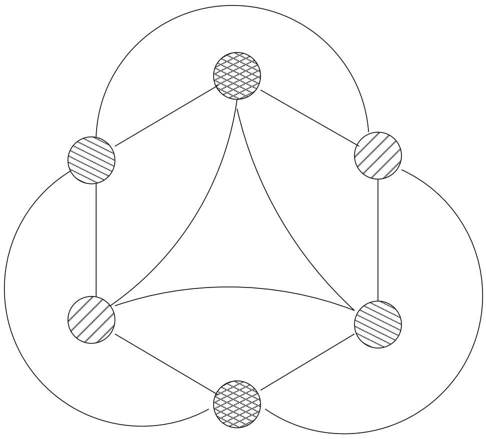

Fig. 2. Interference

We are interested in solving this problem in a decentralized way, as there is no central entity that has the global vision of the network and can magically configure all the nodes. Only *after* the problem has been solved, the network will work and the administrator will be able to collect topology data and remotely configure the network.

In order to solve this problem in a decentralized way, we need that the nodes keep trying different colours until a solution is found. To be more specific, a node will pick the same color if none of its neighbours has picked that particular color. Otherwise it will change the color.

VII. The construction of a beacon schedule

Each station picks a random position in the schedule. If it receives confirmation from all of its neighbors, it assumes that no collisions have occurred and keeps transmitting at that position. This means that no other neighbor in the two-hop neighborhood has picked the same color.

If a node in the two-node neighborhood pick the same color, the node that is a common neighbor of both will not receive the beacon and therefore will not confirm the correct reception.

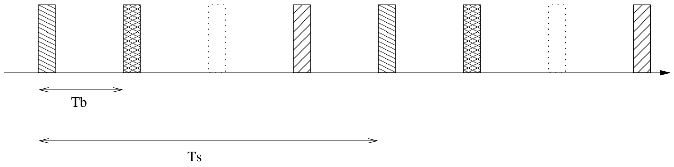

Fig. 3. Timeline

VIII. Distributed Adjustment of the Schedule Length

The beacon interval T_b is the same for all the participating stations in the network and is set by the standard or network administrator. The schedule length should be adjusted according to the node density.

Each node collects information of its perception of the schedule occupation O, which is the ratio between occupied positions and total positions. A position with collision is assumed to be occupied. To this extend it is necessary that the nodes can use energy detection to determine that a position is occupied.

The nodes share this information with their neighbours and then adjusts its own schedule according to the following rules.

- The schedule is doubled if any of the neighbours report occupation equal to 100%.
- The schedule is doubled halved if all the neighbors report occupation higher than 75%.
- The schedule is halved if all the neighbors report occupation lower than 25%.

IX. Data Included in the Beacons

In each beacon, a node includes acknowledgements off all the beacons received in the last schedule, including their position.

For example, node A in Fig. 1 in its second transmission in Fig. 3 includes the following information (assuming that it has received all the beacons correctly):

- Position 0: empty beacon
- Position 1: beacon B
- Position 2: beacon F
- Position 3: beacon A

Each node also includes information of the data that it has stored in its queues for each of its neighbours.

- Position 0: empty beacon
- Position 1: beacon B, 2 outstanding packets
- Position 2: beacon F, 0 outstanding packets
- Position 3: beacon A

A *free flag*. If a station has no data to transmit and no data to receive, it activates the free flag to indicate its neighbours that they can compete for the medium.

Acknowledgements of all the packets received since the previous beacon.

X. The Medium Access Control Protocol

Each station owns the time that follows its beacon until the next beacon spot. It can use this time to transmit packets to its

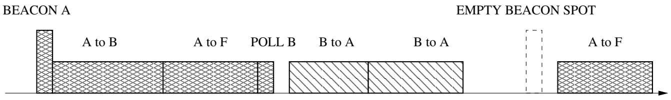

Fig. 4. Medium Access

neighbours and to request packets from its neighbours using *poll* packets.

A station can also indicate that it is not going to use the time that it owns using the free flag.

After empty beacon spots and after beacons with an activated free flag, stations are allowed to contend for the medium using CSMA/CA. During this contention, they are exposed to hidden terminal collisions.

Note that packet transmission is not immediately followed by an acknowledgement as in traditional CSMA/CA. Acknowledgements are delayed and transmitted together with beacons.

A. An Example

An example of medium access is presented in Fig. 4. It shows the access to the medium from the point of view of station A. After transmitting its beacon, station A is free to transmit and request packets from and to its neighbours. In this particular example A transmits a packet to A and then a packet to B. Then, it uses its remaining time to request and receive two packets from A. The two packets are requested in the poll message.

The next beacon spot is free from A's point of view. Therefore A can contend for the medium using CSMA/CA and in this transmission it is exposed to the hidden terminal interference.

Even though it is not shown in the figure, at a later time B transmits its beacon. Then A has to remain silent unless B explicitly requests a packet from A using a poll.

XI. Conclusion

Acknowledgment

The authors would like to thank ...

References

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