Power Aware Alternation: a novel power saving mechanism for ad hoc networks

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Abstract— *Ad hoc networks are composed of mobile nodes without any centralized management entity. The appearance and the disappearance of the nodes are managed in a distributed way as well as the operation of routing, which forces each node to become itself router. There is an important traffic overhead to maintain the network connectivity and to assume the data transmission in spite of congestions. In addition ad hoc networks are characterized by limited energy resources. Considered as one of their critical issues, energy consumption determines and affects the lifetime of the ad hoc networks. In order to reduce energy consumption and increase the lifespan of the network, we propose a novel approach: Power Aware Alternation (PAA). Our work is based upon cooperation between mobile nodes to negotiate on the use of their energy. For some nodes, this cooperation permits to eliminate their network activity during a certain period (called inactive period) while keeping their presence in the network by delegation using some supporters, charged to collect their messages. In this paper we propose two versions of PAA, Synchronous PAA is based on alternation of active and inactive states between supporters at pre-definite periods. Asynchronous PAA requests a negotiation phase between groups of supporters before any entering in inactive state.*

Key Words. Power saving, ad hoc networks, cooperation.

I. INTRODUCTION

Ad hoc networks are composed of independent mobile nodes which form the network topology in a spontaneous way. The topology changes are managed in a distributed way as well as the operation of routing, which forces each node to become itself router. However, routing activities are not the only activities that consume energy. Generally, a mobile must ensure its connectivity to the network through periodic emissions of control messages and listening to the wireless channel. Several work showed that the network activity is very expensive in energy. The emission as well as the reception consumes a significant energy. At the same time limited battery power characterizes the independent mobile nodes. Hence, the consumption of energy is a main issue for ad hoc networks. It is a vital factor for the lifetime of the nodes and so of the whole network. Controlling the energy consumption can be made in several manners and at several levels.

Network activities related to several levels need important energy. At the physical level and data link, to preserve their connectivity at the network, the nodes must listen to the channel and exchange periodically messages of control. For a given geometry, the power used for the emissions determines the nodes being able to be reached by a mobile. Because of the nature of the radio medium, interferences and collisions cause frequent retransmissions. The high density of nodes in the space increases the number of collisions. On the level of the routing activity, participation of intermediate nodes in a routing operation and management of the additional control traffic associated to the routing protocol multiply the consumption of energy.

Considering uninterrupted consumption in energy of the active nodes and in order to increase the lifespan of the network, we propose a new mechanism for the conservation of energy. Our proposition is based on the elimination of any network activity of the nodes which participate to this power save for certain periods. In order to decrease latency and to assume their accessibility, their presence in the network is keeping by delegation. Each node will be supported in its absence by other supporter nodes charged to recover the messages towards the inactive node. The goal of the mechanism will be reached because it will not only preserve the energy of the participating nodes but also decrease the interferences and consequently the losses of the packets due to the density of the active nodes in the network.

The rest of the paper is organized as follows. In the following section, we present the most important approaches and mechanisms already existing for the conservation of energy in ad hoc networks. We expose in the third section our proposal to decrease the consumption of energy. The collaboration of the participating nodes can be synchronized or an asynchronous functioning can be also implemented. The two organizations are presented in the paper. We finish by a conclusion.

II. RELATED WORK

The most important propositions for energy conservation in ad hoc networks consider the physical, the data link and the network layers. Some propositions aim to improve and control the physical conditions of the data transmission as the range of the mobiles. Other solutions are situated on the data link level and there are numerous routing protocols which take into account the power state of the nodes.

In [2], the author state that the power consumption depends on the amount of emitted bits and the distance that separates the two communicating nodes. The power of transmission has a direct impact over the lifespan of the batteries and on the capacity of the network in term of throughput. Indeed, [3] shows that the larger the range of the nodes is, the more the power necessary to the transmission is large. Moreover, to increase the range, also implies to increase the probability of interference, the rate of collisions and losses. In certain cases it can decrease the capacity of the nodes which will transmit. Power control consists in adapting the ranges and the powers of transmission of the nodes in order to ensure a minimal consumption of energy while keeping the connectivity of the network. The optimal range of transmission could be common for the nodes of the network [6][14] or not. It aims at reducing the range of the nodes, and thus to reduce the interferences and the collisions and to allow a better conservation of energy [1]. Several proposals exist to ensure the power control [8][12].

At the MAC layer, energy is consumed by control operations. The mobility of the nodes generates frequent topology changes. This increases errors, packets losses and leads to frequent retransmissions. To economize energy, S-Mac [13] allows nodes to enter in sleep mode for long periods. In S-Mac, a node can enter in sleep mode when one of his neighbors is transmitting. T-Mac [11] extends S-Mac by adjusting the period of sleeping mode according to surrounding communications. This reduces the power consumption leaded by the passive listening to the channel. Other proposals [7][9] are based on two channels architectures. They ensure a conservation of energy through the deactivation of a first channel and the use of the second at minimum capacity just to awake a specific neighbor or to listen periodically to the channel.

802.11[16] defines PS (Power Save) mode to preserve the energy of the nodes in a wireless network. A node, announces its willing to enter in sleep mode. In infrastructure mode, the access point authorizes the station to enter in sleep mode and stores the messages in its destination. The station must listen periodically beacons generated by the access point. This one includes in its beacon TIM (traffic indication map) that indicates the stations for which it has stored packets. A station must remain in its current state until it informs the access point.

A station can then have one of the two following states:

- Awake: the station uses all its power.
- Doze: the station is unable to transmit or to receive; it uses the minimum of its energy. 802.11 defines two modes of energy management:

Active mode (AM): the station can receive packets at any moment. It is in the awake state.

Power Save (PS) mode: the station listens to Beacons and sends a PS-poll to the access point if the TIM of the most recent beacon indicates that the access point has messages buffered for it. In this mode the station must be in the state doze then in the awake state to receive beacons, to send PS-poll and to receive buffered packets.

In ad hoc mode, synchronization is done in a distributed way. Each node must generate a Beacon periodically if it does not hear another beacon during the Beacon_Interval period. If a Beacon is received, other stations cancel sending of their Beacon and synchronize them selves according to the time stamp of the received Beacon. A station can enter in mode PS for a Beacon_interval. Other stations locally keep the messages bound for a node in mode PS. Buffered packets must be announced by an ATIM (Ad hoc Traffic Map Indication) transmitted during the ATIM window. PS mode operates as follows in an ad hoc network:

- A station enters in state doze.
- During an ATIME_Window interval, the station returns in awake mode to listen to Beacons. If during period ATIME, a station does not receive any advertisement for packets, it returns in doze mode. If it

does not, it must remain in awake mode until the end of Beacon_Interval.

- After ATIME, only the packets, which were announced successfully, are transmitted to their recipients. The transmitters as well as the recipients must remain in state awake until the end of Beacon_Interval to finalize their exchange.

Awake synchronization makes the weakness of PSM. In fact, all nodes are supposed to enter in doze or awake state at the same moments. This has several effects especially on routing activity which could suffer important delays in case of routing through a whole inactive cloud of nodes.

Another approach for the energy conservation consists in considering the energy consumed for the routing activities. In some routing protocols, the power consumption and the capacity of the batteries are used as metrics for the choice of routes. In this context, MTPR (Minimum total Transmission Power Routing) [10] allows to choose the route minimizing the overall consumption of energy by considering that the best one is that having the node with the minimum battery capacity. MBCR (Minimum Battery Cost Routing) [11] considers that the remaining capacity of the batteries reflects better the lifespan of a node and chooses the route which maximizes the remaining capacity of the battery. MMBCR (Minimum Maximum Battery Cost Routing) [11] chooses the route which bottleneck has the maximum remaining capacity (the node having the minimum of remaining capacity). CMMBCR (Conditional Max-Min Battery Cost Routing)[13] proposes to limit the minimal remaining capacity of a set of routes then applies MTPR. This will ensure the choice of a route that the minimal remaining capacity is above a certain limit and hence minimizes the consumption of energy.

III. Power Aware Alternation protocol

The majority of the studied proposals for energy conserving are based on the uninterrupted presence of the nodes in the network. However, the impossibility of the simultaneous emissions in the neighborhood of a node indicates the possibility of an organization that enables some nodes to enter in an inactive state. In our model we consider that the consumption in energy of the active nodes is uninterrupted. In order to increase the lifespan of the network, we propose a new mechanism for the conservation of energy. This proposition is based on the elimination of any network activity (as in PS mode using 802.11) of some nodes for certain periods while keeping the presence of these nodes in the network by delegation. The economy is carried out by disabling any network activity of the node which will be supported in its absence by other nodes charged to collect its messages. This mechanism will not only preserve the energy of the participating nodes but also it will decrease the interferences and consequently the packets losses due to the density of the network. This last objective is carried out following the reduction in the number of active nodes at a given moment. We present in what follows the details of this new protocol that we baptized PAA or Power Aware Alternation. This protocol defines the mechanism of the negotiations in order to organize the nodes of the network in a virtual network of groups of supporters. To organize the cooperation of the machines, we defined two different modes for the PAA functioning. Synchronous mode imposes predefined and fixed activity and inactivity periods for all the nodes of the network. In the asynchronous mode each change of state must be negotiated within a group of supporters.

A. *Previous work*

In [4] we proposed the synchronous version of PAA. Before the cooperation of nodes, PAA needs the organization of the nodes in a virtual network of groups of supporters by a phase of negotiation.

Construction of the virtual network of groups of supporters

A node can launch a request to obtain a supporter only if it doesn't have any one. Several nodes among its neighbours can reply to its request. A node must then choose one supporter between candidates according to their level of energy. With the emission of the request, the node starts a timer T. If at the end of this timer no message of acceptance is received, the node diffuses another request and resets the timer. This process is repeated until obtaining one or more acceptances. If at the end of the timer the node receives several acceptances then it chooses only one among the candidates and returns a message of confirmation to it. The algorithm of choice is based on the selection of the node having the best level of energy. If only one acceptance is received, the node sends back the confirmation without executing the algorithm of choice. The request must carry the energy level of the node and is diffused to the neighbouring nodes only.

Following the reception of a request for obtaining a supporter, a node can choose to accept this request or not. If the node does not have any supporter and he wants to get involved with this cooperation, then it accepts directly and becomes candidate, if not, it checks if its energy level enables it to support an additional node or not. At this end, we defined N the maximum number of nodes which can be supported by a node. Once a node agrees to become a supporter, it must generate a message of acceptance towards the node having emitted the request. This message must include the number of nodes that it currently supports and its energy level. Once the node chooses its supporter, it sends a message of confirmation to him. It creates a queue that will store the messages of the chosen supporter, and then synchronizes itself to the network. It starts to apply the periods of the clock only after the reception of the acknowledgment. With the reception of the message of confirmation, the new supporter creates in his turn the queue relating to the first node, sends back an acknowledgment and directly begins the activities related to the support of its supporter.

Functioning in synchronous mode

After organising the network in groups of supporters, all the nodes activating synchronous PAA are synchronized according to a centralized clock. Fixed periods are dedicated for the inactivity or the activity state. Supporters within the same group alternate active and inactive states. During a period, an inactive node disables any networks activity. Its supporters collect and buffer the messages towards it. At the end of the period, the node gathers the messages buffered for its from its supporters. In the figure below, we describe the alternation between active and inactive states between two supporters.

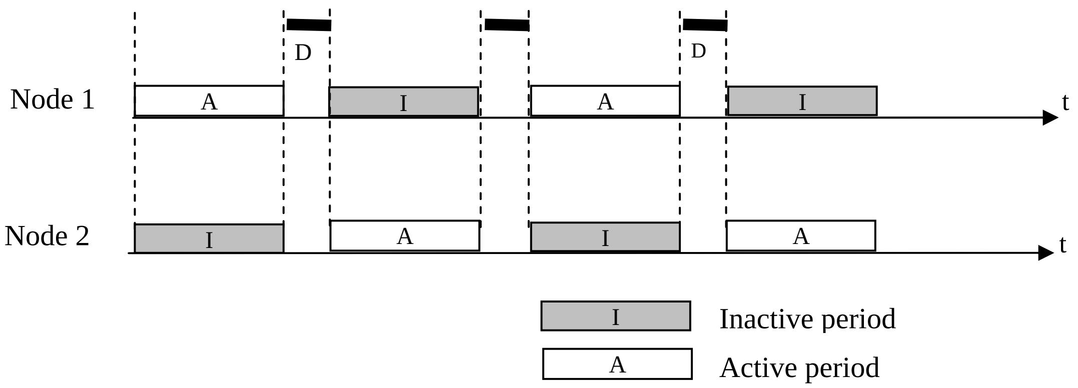

Fig. 1. Alternation between active and inactive mode

The period D is selected such as it allows the nodes which leave the phase of inactivity to recover their messages from their supporters. It must be sufficient to take account of the network conditions and the necessary time to transmit the queues of messages.

B. Asynchronous PAA

Contrary to the synchronous mode, the asynchronous mode does not require a synchronization of the nodes of the network. Negotiation for obtaining a supporter follows the same process as in synchronous mode. However, unlike the synchronous mode, we don’t define any limit for the number of supporters that a node can have. A node accepts a request to become supporter only if its energy level allows him. The entry in inactive or active mode also passes by a phase of negotiation. A node can request an entry in active mode only if:

1) The node has at least one supporter.
2) The node is not engaged in supporting one of its supporters at that moment. A node is said to be engaged in supporting if it is collecting the messages of one of its supporters which is in inactive state at that time.

If these constraints are satisfied, the node diffuses a request for inactivity to its supporters. If it receives at least one engagement (one of its supporters engages to collect its messages) it is authorized to become inactive. In this case, it must inform all its active supporters by its new state. Within the reception of this notification, the engaged node sends back an acknowledgment and starts buffering messages. As soon as the first node receives the acknowledgment, it enters in inactive mode. This mechanism is illustrated in Fig. 2.

This figure shows a node I, which has 3 supporters J, K and O, diffusing a request for inactivity. Only node J replies and engages to support it by its next inactive period. Node I diffuses a notification to all its supporters to notify them by its next change of state and the engagement of node J. Node J replies by an acknowledgment and starts collecting node I messages. At the reception of the acknowledgment, node I enters in inactive mode.

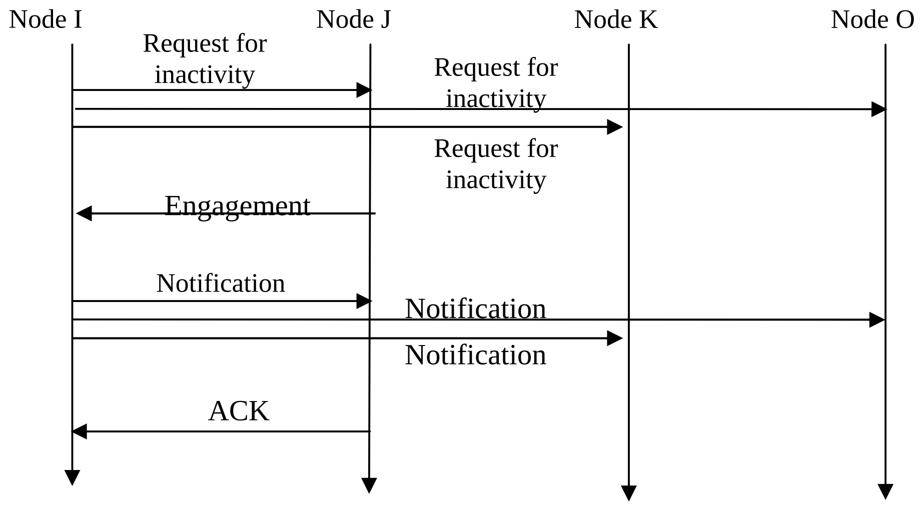

Fig. 2. Negotiation for inactivity entry

If several nodes rely to a request for inactivity, the requesting node accepts all engagements.
At the reception of a request for inactivity from one of its supporters, a node can:

1) Accept to support the requesting node for its next inactive period. In this case, it must send an engagement. A node can engage only if its energy level allows it and if it is actually engaged towards less than N inactive nodes.
2) Ignore the request by sending any reply if its engaged towards N inactive nodes or it has a critical energy level or it wants to enter inactivity at its turn.

A node cannot enter in inactive mode in the following cases:

1) If it is engaged at least to one of its supporter.
2) If none of its supporters agrees to engage to its.
3) If it loses all its supporters.

In the first case, the node must wait until all its inactive supporters, towards them it is engaged, awake then to make its request. In the second case, the node must retransmit periodically its request until obtaining an answer. In the third case, the node must launch a new request for obtaining a supporter.

IV. Discussion and Conclusion

In this paper we proposed a new mechanism for energy conservation based on removing any network activity of a node for certain periods. The participating nodes of the network can alternate activity and inactivity states.
We defined a synchronous and an asynchronous mode for the functioning of this mechanism.
Synchronous PAA has the advantage of being simple to implement. Indeed, once the negotiation for obtaining the supporters is established, each node is synchronized to the rest of the network and follows the periods granted to him to enter in activity or inactivity states. This does not induce any control messages since the nodes do not need to communicate to diffuse their states. This version has the advantage of being scalable as the increase in the number of supporters of a node (which is however limited by N) does not introduce any additional traffic into the network.
Asynchronous PAA is more suitable in case of very active networks where several nodes can’t enter frequently in inactive states. It offers more flexibility because nodes can negotiate the length of their inactive periods. An other advantage of the asynchronous cooperation that synchronisation of mobile machines id not needed.

We intend at evaluating the performances of this mechanism in term of added traffic and in term of real energy preserved through an implementation under J-Sim[15]. Future work will aim at distinguishing suitable use cases or scenarios for each version of PAA and at defining the optimal parameters for each one.

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