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# Energy management in WSN: IEEE 802.15.4 unslotted mode

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**Abstract**—Wireless Sensor Networks suffer from many problems but energy efficient always presents the most critical trouble in this field. Many approaches and technologies were invented in order to reduce the energy consumed such as the IEEE 802.15.4. The IEEE 802.15.4 is invented for low power and Low Rate Wireless Personal Area Networks (LRWPANs). It has been updated many times in order to provide a suitable solution for this problem. It presents two different modes which are the beacon enabled mode and the non beacon enabled mode. This work is interested in the non beacon enabled mode. The paper proposes a new model to compute the energy consumed by the node in the CSMA/CA protocol specially in the unslotted algorithm. Then an auto-adaptation process is enabled. So the last quantity of energy in the battery is adapted to the activity period of the node in the network by intervening in its duty cycle in order to postpone its death. The simulation results prove both the efficiency of our consumption energy model in addition to the performance of our intervention which lead to reduce the consumed energy by node and to increase its lifetime.

**Keywords**—WSN, Duty cycle, IEEE 802.15.4, Energy, unslotted CSMA/CA.

## I. INTRODUCTION

In this last years, the Wireless Sensor Network (WSN) succeed in attracting the attention of both the industrial and the research centers. WSN is constituted by a hundreds of low power nodes which characterised by theirs excellent sensibility. Many troubles could be affect the wireless communication such as the energy problem which due to the little battery capacity of the node. Many approach and methods were invented in order to resolve this problem such as [1], [2], [3], [4] and [5]. It could be divided just on three groups: preamble sampling protocols, time-division multiple access (TDMA) based protocols and protocols with common active periods [6]. The sensor nodes could not be recharged which contributes to a big problem in the wireless communication. An important quantity of energy is consumed in the transmission phase. The radio energy consumption is considered as the main origin for energy wasting in each node of the network [7].

Therefore setting the radio in sleep state presents the idol state to conserve energy of the node which is the subject

of the most important MAC protocol. In this case the node is enable to send and receive data with other members of the network. Moreover, in wireless sensor network the node have many sleep states such as the case of the the CC2420. It supports three different states. The deepest sleep mode consists on switching off both the oscillator and the voltage regulator in order to generate the lowest current value in all low power modes. However the lightest sleep mode is the state of the radio when the node change its state from the active state to inactive state. It is about a few energy lost. In the LRWPANs, it is better to adopt the deep sleep mode in which the node waste more time on sleeping state. Although in the high traffic load, the lighter sleep mode is more adequate [7]. Wireless Sensor Networks is enabled in many applications due to its importance such as industrial applications [8], environmental application [9], building application [10], physical security and transportation [11] in order to sense such parameters like the pressure. Many approach are based on the duty cycle of the nodes. It could be divided on two main categories which are the synchronous and the asynchronous method [7]. Synchronous methods like the SMAC and the TMAC. The main idea is to specify a scheduler instant to send in it the data from the node to its neighbours. Asynchronous protocols are ones which depend from the preamble sampling such as the BMAC and the X-MAC. Using this kind of the paradigm the node is obliged to receive a wake-up message periodically. Our work consists mainly on presenting another model for energy consumption in the first step. Then, based on the lasted energy level on the battery of the node, we make a decision to conserve the current duty cycle or change it to another. The paper is organized as follows: the first section is dedicated to present an idea about the topic of the paper. In the next section an idea about some literature works were provided. In the third one a general overview of the IEEE 802.15.4 is exposed. Regarding section 4, it is designed to give a clear model for the energy computing. Then simulation result are presented and discussed. Finally, a small conclusion is provided with some perspectives.

## II. RELATED WORK

There are many algorithms developed in the literature such as the B-MAC. The B-MAC presents an asynchronous approach [12]. This technic is based on the phenomena of sleep/active duty cycle without taking in consideration the scheduling of this operation. So the node is waking up after every period in order to control the availability of the transmission canal. The B-MAC protocol defines 8 periods every one corresponds to a one of the 8 listening modes which its time of reception is bigger than the check duration. There are 8 different preambles which depended from the transmitted modes. The X-MAC is an amelioration of the B-MAC approach [13]. So it is also an asynchronous protocol. It is characterised by its less energy consumption in addition to its preamble length. When the node receive its message it transmit an acknowledge ACK. This method leads to minimise the time lost in sending the preamble which is based on the overheard of the canal of transmission. The X-MAC is based on using a short preamble length which combine the low power listening, the simplicity in addition to disjoint both the transmission and the sleep period of the receiver.

The duty-cycle problem was studied in many works such as in [7]. The authors use the energy consumed in order to make the best decision about the best route used in order to reduce the energy consumed by node which lead to maximize its lifetime. Although this approach suffers from such limits such as it didn't take in consideration some important parameters such as the collision of the data, random access to the transmission canal in addition to the delay needed to change the state of the node. Moreover the adaption is based on detecting the current level of energy in the node and its neighbours.

In [14], the authors proposes two different approach which deal with the adaptation of the duty cycle. The first methods presents a dynamic duty cycle which depend specially from the time lost in waiting the packet. The second method interests in the energy consumed in the network. Both algorithms depend from the inter-arrival time of the data's traffic in the network, which is not known in advance. In order to resolve this problem the authors used a learning algorithm which deal with estimating the probability distribution.

Also, in [15], the authors propose two others duty cycle algorithms called asymmetric additive duty-cycle control (AADCC) and dynamic duty-cycle control (DDCC). The first one is about a linear variation (increase or decrease) of the duty-cycle depending on the comparison of the number of packets which are really received. In the case that five consecutive packets are successfully received the sleep duration will be decreased by 0.1s. Although in the second method the authors search to adequate the energy consumed with the reliability. Then a simple intervention was executed and the duty cycle was updated with the noisy of the system.

In [16], the writers are interested also in the energy trouble of the network. So the optimal duty cycle was also a good solution unorder to control the lifetime of the network. However in [17], a statistical sensing coverage is presented.

The different parameters of the system such as the expected k-coverage periods, the stationary coverage probability and the expected k-vulnerable periods extracted from the renewal process theory.

All the cited works are interested in selecting the most convenable value of the duty cycle in order to protect the last quantity of energy without making attention to well computing the quantity of energy consumed by node. The choice of duty cycle presents the second step. The first step is computing the energy wasted by node which is not developed in the cited work. They used a classic model to get it without mind to the efficiency of the results they get. But in our work, we present a new model for energy consumption which presents all the states of the node in its communication with other nodes. Then, based on it, we decide about the value of the duty cycle.

## III. IEEE 802.15.4 STANDARD

The technology of the IEEE 802.15.4 is designed to resolve many problem which are attached to the communication troubles.

The IEEE 802.15.4 could manipulate in two different modes which are the beacon enabled mode and the non beacon enabled mode. With respect to the beacon-enabled mode, the data frame include a beacon frame, Contention Access Period (CAP), Contention Free Period (CFP) along with an inactive period. The CAP is composed by 16 slots and enabled by Collision Avoidance Carrier Sense Multiple Access (CSMA/CA). All node share the same frequency channel. However the CFP is equipped by Time Division Multiple Access (TDMA) protocol. The CSMA/CA protocol provide a good chance to avoid energy lost with reducing the collision state between the messages which lead to avoid the retransmission of message between nodes. In addition to that the CSMA/CA contributes also in minimizing the network attending traffic over regular access to the transmission channel. The CSMA/CA protocol succeeds in reaching its efficiency with its both modes the slotted and unslotted modes. The first kind is always enabled through the beacon-enabled mode. Although the second is regularly adopted by the non-beacon enabled method [18].

On applying the unslotted CSMA/CA, data packets could be sent any time without any synchronization needed. A short description is provided below in figure 1 in order to explain the IEEE 802.15.4 technology in non beacon enabled mode in transmitting data. The first step is about initializing the different parameters the NB to 0 and the BE to the  $macMinBE$ , then a random backoff is generated which is included between (0 and  $2^{(BE-1)}$ ) in bit to initialize the timer. After that the canal state of the wireless medium is tested by sending a Clear Channel Assessment (CCA) as presented in figure 1. If it is already free then the data will be send to its receiver if not, the state is updated as presented below  $NB = NB+1$  and  $BE = \min(BE+1, macMaxBE)$ . In the case that the number of the backoff exceed the value if the  $macMaxCSMABackoffs$ , the data will be dropped [19]. There is an optional mechanism which could be permitted by the CSMA/CA non slotted algorithm which is the retransmission mechanism based on

the acknowledgements and timeouts. When it is enabled the destination node must send an acknowledgment as a response to its data sender in order to confirm its reception. On the other side if this acknowledgment is received after a defined time, the packet is retransmitted in other time unless it reach the  $macMaxFrameRetries$  1.

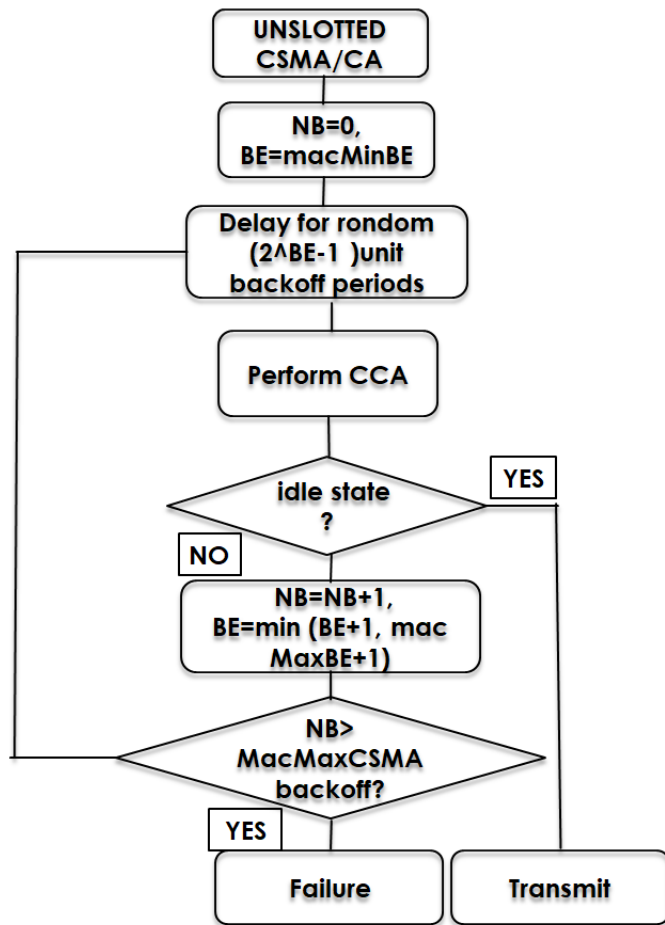


Fig. 1. CSMA/CA unslotted version

Thus, in the IEEE 802.15.4 associated technology, each node appears to be constituted of a physical layer formed by a radio frequency characterized with a low-level control mechanism. Additionally, there is also the medium access control sublayer (MAC), which represents the unique gate for the physical layer. Besides, two extra layers do also persist, namely, logical link Control (LLC) along with the Service-Specific Convergence Sublayer (SSCS), with the upper layer. Regarding the physical layer, it is allotted with the accomplishment of two major roles: the PHY management service dubbed PLME (Physical Layer Management Entity), as well as the PHY data service responsible for exchanging the PHY protocol data units (PPDUs), through control of the link quality indicator (LQI), energy detection (ED), Clear Channel Assessment (CCA) for the csma/ca protocol, along with the channel frequency selection task [20]. Noteworthy,

also, the MAC layer incorporates two main service tasks, namely, the MAC management service defined as MLME (MAC Layer Management Entity), along with the MAC data service, enabling to maintain exchange among the various MAC protocol relating data units (MPDUs). Regarding the MAC structure, four kinds of frames could be distinguished: the data frame, beacon frame, MAC command frame as well as the acknowledgement frame, dedicated to ensure the data reception conforming process.

#### A. Transmission limits

In so far as it provides several advantages, Wireless Sensor network also displays a number of drawbacks and limits. For instance, on applying the CSMA/CA protocols, the BE selection turns out to be randomly implemented, with no careful heed being paid to the transmission channels availability and real potential. Additionally, the cited standard seems to give no great importance to the information urgency aspect, in that it does not actually provide any clear or effective means whereby data actual urgency level, as sent by the different modes, can be revealed in such a way as the transmission channel access priority can be allotted to them. Among the extra noticeable drawbacks this technology appears to display, there lies the serious problem of interference. Like many other applicable standards, the IEEE 802.15.4 standard utilizes the same type of frequency band (the 2.4 GHz), along with the 802.11 (WLAN) and the 802.15.1 (bluetooth). Consequently, several research works have been conducted for the purpose of solving the problem of maintaining an effective coexistence of different technology modes. In this respect, several authors undertake to make use of one of the two methods put forward to deal with such a problem. The first advanced solution proposes using the mediator interference, which consists in implementing a coordinator method lying between both of the WLAN and Zigbee alternatives. Other research groups propose an adjusting alternative, whereby the CCA value could be adjusted in the case of predominating high interference level. In this regard, three possible scenarios have been investigated, liable to culminate in the setting up of a new approach. Indeed, the latter turns out to involve two major phases, namely, the detection phase as well as the avoidance phase. Concerning the first phase, it rests heavily on a simple comparison of the transmission failure along with the energy levels, as persisting in the channel, with an optimally predefined threshold.

Noteworthy, however, some other suggested algorithms appear to favor adoption of a second alternative allowing for a jointly efficient marriage of such technologies. As a matter of fact, they turn out to classify the WSNs into both interfering and non-interfering sets. While the first set is intended to specify the WSNs encompassing the highly remarkable interference level, the second is conceived to englobe the low interference level set. Indeed, a great number of interested authors seem to be interested in both of the single as well as the multi-channel scenarios. Others appear to be rather interested in adopting the virtual channel transmission mode. In effect, the latter turns out to encompass a twofold step,

involving two schedulers and a virtual channel selector (VCS), useful for helping identify the most optimum channel available. Eventually, however, a number of limitations have been discovered to prevail with respect to the IEEE 802.15.4 mode, mainly, the unbounded delay noticeable in disseminating information until destination. Besides, the advanced framework proves to exhibit the serious problem of persistent low-delivery rate. Noteworthy, also, is that the multi-hop topology (tree topology) appears to impose keeping the node associated radio on a perpetual operating mode, which is likely to result in a remarkable energy amount being consumed or wasted.

#### IV. ENERGY EFFICIENT

The emission energy  $E_{em}$  presents the quantity of energy lost by node in order to send its data other nodes of the network. This particular procedure is presented through the equation (1), appearing below.

$$E_{em} = nb_{send} * Eb \quad (1)$$

( $Eb$ ) presents the binary energy. Although ( $nb_{send}$ ) express the number of bit of all the frames send by node.

Even in receiving frames the node consumes some quantity of energy named ( $Erc$ ) which is expressed by formula (2).

$$E_{rc} = nb_{received} * Eb \quad (2)$$

With ( $nb_{received}$ ) is the number of all bits received by node. The energy consumed in overhearing and overmitting phase, is mentioned by equation (3).

$$E_o = nbr_{tr} * dtra * Eb * PER \quad (3)$$

$nbr_{tr}$  denotes the number of bits transmitted by node. ( $dtra$ ) shows the size of frame (bit). While PER is the error rate which is obtained as the average of packet transmitted without being well received.

Concerning energy in collision state ( $E_{col}$ ), it is computed by expression(4).

$$E_{col} = Nbr_{ck} * Zpck * Eb \quad (4)$$

( $Nbr_{ck}$ ) is the number of collision.  $Zpck$  presents the size of the packet transmitted in the network.

In the non beacon mode of the IEEE 802.15.4 the nodes communicate each other through the csma/ca unslotted algorithm. In this kind of networks all the nodes have a period of activity and a period of sleep in which the node are not enable to transmit or receive data except the coordinator which is supposed active all the time. The period of sleep helps in reserving the energy of the nodes ( $E_{SLP}$ ) which is giving by formula below (5).

$$E_{SLP} = U * I * PS \quad (5)$$

$U$  is the voltage value,  $I$  defines the current value and the PS presents the sleep period. The energy consumed in idle state is presented by equation (5).

$$E_{idle} = Db * U * I \quad (6)$$

$Db$  presents the all the duration of backoff state.

The purpose of the presented work work is to control the last quantity of energy in the battery of nodes in order to postpone the its death which lead to maximize the lifetime of the network. So when the energy reach very critical value, a quickly intervention is activated by changing the duty cycle. The first step is estimating the energy consumed by node ( $E_c$ ) presented by formula (7) then computing the energy remaining ( $E_R$ ) giving by expression (8). The second step is about adapting the duty cycle of nodes.

$$E_c = E_{em} + E_{col} + E_o + E_{SLP} + E_{rc} + E_{idle} \quad (7)$$

$$E_R = E_{ini} - E_c \quad (8)$$

#### V. IMPLEMENTATION AND SIMULATION RESULTS

This work is implemented by the OMNET++/INETMANET simulator. This simulator is well known by its numerous advantages. It is considered an open-source network simulator. In addition to that OMNET++ is noted by its graphical tools and its hierarchical models. It supports also a very developed environment which teaches all the layer of the nodes. It is an oriented object modular with discrete event network simulation used for both the wired and wireless networks. INETMANET framework is also an open-source model [21].

Our simulation parameters are mentioned in table 2. So as mentioned above, we start by estimating the energy consumed by nodes. After that the energy remaining in the battery is detected and based on its value the decision of intervening is made. In our case the duty cycle of the node is reduced from 50 percent to 25 percent which lead to minimizing the energy consumed by the node in every time.

TABLE I  
SIMULATION PARAMETERS

Parameters	Values
Simulation time (s)	3600
Coverage area	(600,400)
E initial (J)	18720
Nodes number	24
PAN number	1
Channel frequency	2.4 GHz
MAC layer	CSMA/CA
Topology	Tree
dispersion	random

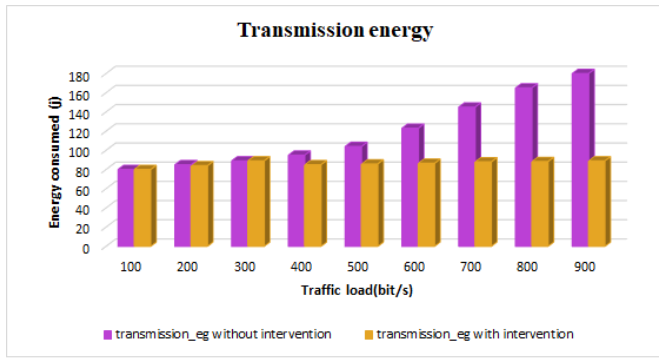


Fig. 2. Emission energy in unslotted CSMA/CA

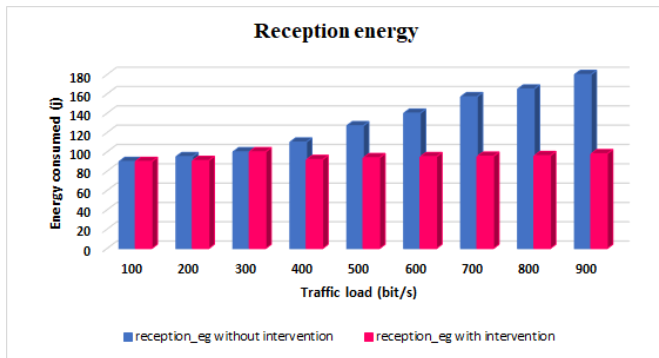


Fig. 3. Reception energy in unslotted CSMA/CA

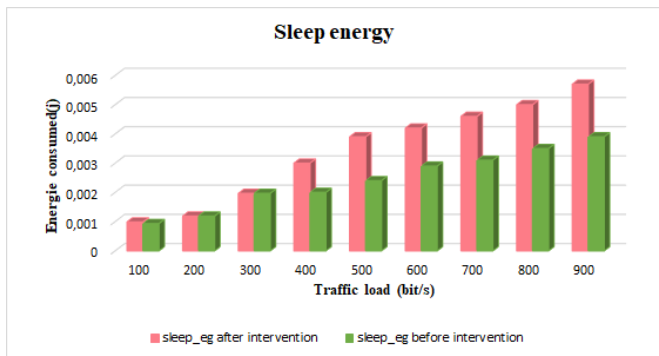


Fig. 4. Sleep energy in unslotted CSMA/CA

The network is composed by 24 nodes which are all controlled by the coordinator node which are organized with a tree topology. The coordinator node is supposed all time an active node. Although the other nodes of the network have a sleep period blessing to the duty cycle which is equal to 50 percent. After reaching the energy's value of 200j, an auto-adaptation is started. So the duty cycle of all nodes of the network is updated and changed to 25 percent. The different simulation results are presented below: the emission energy, the reception energy, the overhearing and overmitting energy, sleep energy and the idle energy.

The figures 2, 3 show that the energy of reception mode and emission mode are decreasing by the same way. Although, the

energy of sleep mode is presented by figure 4. It is increased after our intervention because the period of sleep is increased in order to protect the lifetime of the node. The energy of

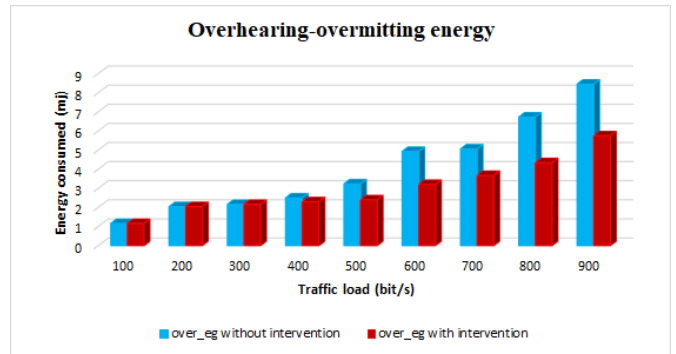


Fig. 5. Overhearing and overmitting energy in unslotted CSMA/CA

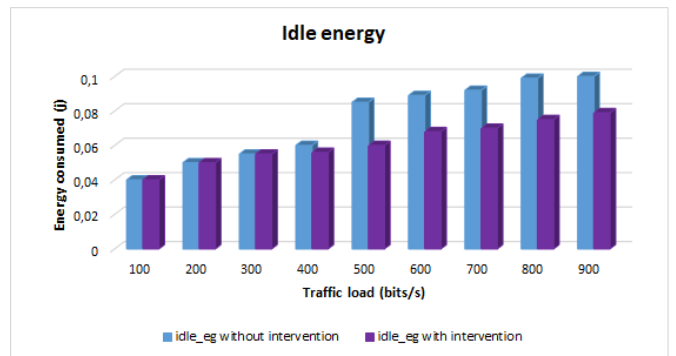


Fig. 6. Idle energy in unslotted CSMA/CA

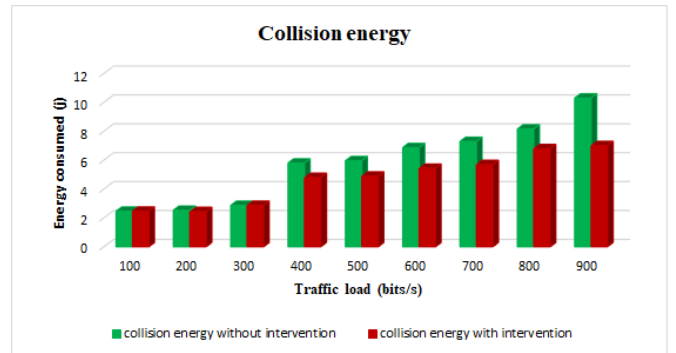


Fig. 7. Collision energy in unslotted CSMA/CA

overhearing and overmitting (figure 5) and the energy in idle state (figure 6) in addition to the collision energy (figure 7) are all declining with the increase of the traffic load which present the best proof of the efficiency of our intervention in this moment. The auto-adaptation presents very interesting solution for the energy trouble in wireless communication network because in most case these networks are inaccessible by both

research groups and the engineers of the society because of the application area.

## VI. CONCLUSION

This work propose a reliable energy efficient model which deals with the non beacon mode of the IEEE 802.15.4 specially the unslotted algorithm of the CSMA/CA. This model is about a mathematic equations which model the different energy consumed by nodes in all states: emission, reception, overhearing and overmitting, collision, sleeping and idle state. All the node's modes are studied and presented by this way in order to push the efficiency of computing the energy consumption. Our major goal consists in making an auto-adaptation between the energy lasted in the battery and the activity of the node. In order to present our approach the INETMANET/OMNET++ simulator is used. The simulation results prove without doubt that our goal is reached. So all kinds of energy consumed by node is decreased except the sleep energy such as the case of the energy lost in the transmission state which decrease from 5,54J to 4,33J when the traffic loads reach 900 bit/s. As perspective proposition for the presented work, a multi-thresholds approach presents a good challenge to discover.

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