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Multi-Channel Scheduling Protocol for Wireless Personal Area Networks IEEE802.15.4

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Abstract: **IEEE802.15.4 is a standard which specifies the physical and medium access control for low-rate, low-cost, low-power Wireless Personal Area Networks (LR-WPANs). However, this protocol suffers from several types of collisions; In spite of being able to avoid data packets colliding with each other by using CSMA/CA, the risk of beacon collisions still remains specially in a cluster-tree network topology that exist more then one coordinator. In order to solve this problem, we propose a novel fixed channel management scheme using MCSP (Multi-Canal Scheduling Protocol). The key objective in this work is to minimize energy consumption within the network by reducing the effects of collisions that may occur if the clusters operate on the same frequency. By using a newly proposed method, MCSP use two beacon avoidance mechanisms: it starts by the fact of dividing of the hole network into a number of sub networks according to the number of the channels exists in order to avoid the inter sub networks beacon frame collisions inside, and in other side, it use the mechanism of beacon frame scheduling for each sub network in order to avoid the intra sub networks beacon frame collisions. We also evaluate the performance of the proposed scheme through simulation. The simulation results demonstrate that the proposed scheme can minimize the possibility of beacon collisions by efficiently managing the multiple available channels. while the dissipated power consumption of PAN coordinator that uses MCSP is more than the PAN that use the classical IEEE 802.15.4.**

Keywords: *IEEE 802.15.4, Wireless Personal Area Network, LR-WPAN, Zigbee, Wireless Sensor Networks.*

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1. INTRODUCTION

IEEE 802.15.4 is a standard which specifies the physical and medium access control for low-rate, low-cost, low-power Wireless Personal Area Networks (LR-WPANs) [1]. Nowadays, due to its advantages of low power and low cost, IEEE 802.15.4 is widely used in a large number of applications such as health care monitoring, wireless sensor networks, and several industrial automation fields.

In the future, it is expected that the number of applications utilizing IEEE 802.15.4 will increase exponentially. However, this phenomenal popularity has also led the indiscreet deployment of WPANs. Therefore, networks based on this standard are not always free from the danger of collisions of several types. In spite of being able to avoid data packets colliding with each other using CSMA/CA, the risk of beacon frame collisions still remains especially in a cluster-tree network topology in which it exist more than one coordinator. This specific kind of beacon collision problem is caused by a lack of available logical channels. This problem becomes more serious in the case where some of the devices are located between two or more coordinators. On the other hand, IEEE802.15.4 provides

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multiple frequencies represented by 16 channels at the 2.4GHz band and 10 channels at the 902/928MHz band as what is showed in the Fig. 1.

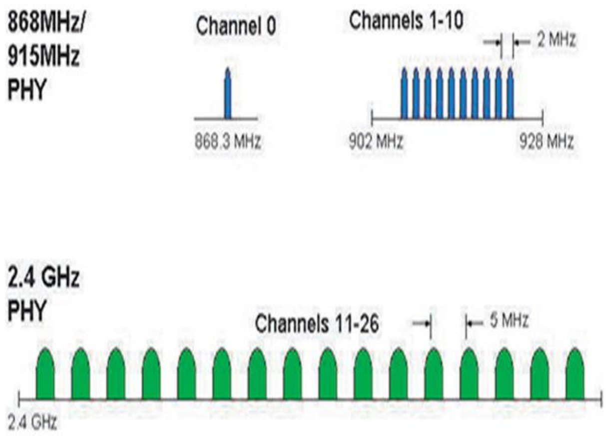

Fig. 1. IEEE802.15.4 fréquence bands.

So it is imperative to design multi-channel communication protocol based IEEE802.15.4 to improve the beacon frames collisions avoidance and network throughput.

With the recent increase in the importance of the beacon collisions problem which can be divided into two types: direct and indirect beacon collisions, several possible solutions have been proposed. These can be divided into two categories: reactive and proactive methods. The first method has not proposed any solution against the indirect collisions beside of the longer time used in the recovery operation of the collided beacon frame, however, the second has not provided substantial solutions to this problem due to their inherent limitations. In order to solve the various beacon conflict problems, in this paper, a new concept called MCSP (Multi-Canal scheduling Protocol) which is a proactive method with a fixe channels assignment. The proposed MCSP can minimize the possibility of beacon collisions by efficiently managing of a small number of the available channels in a fixe manner that appear the most adaptable manner for the protocol IEEE802.15.4. The rest of this paper is organized as follows. First, in Section2, the beacon frame collision problems in WPANs are introduced. In Section3, the related works about the beacon collision problems is provided. Then, in Section4, the multi-channel communication in WSNs is presented. Section5 shows the basic idea and operation of MCSP algorithm to solve the beacon collision problem. In Section6, the simulation results are presented. Finally, this paper is concluded in Section7.

2. BEACON COLLISION PROBLEM IN WPANs

A beacon issued by a coordinator, periodically or by request, plays an important role in constructing a WPAN and in synchronizing of all the devices in the network. Due to the punctually importance of issuing the beacon frames, they have the highest priority in the network. Therefore, unlike in the case of normal data or control packets, carrier sensing or back-off algorithms are not used for beacons, except for their initial transmission. However, it is possible that a number of coordinators in the same WPAN transmit different beacon frames in order to manage their proper clusters. In this case, since the standard does not provide any method of mutual information exchange, collisions may occur between this beacon frames. Therefore, it might result in unexpected network panic. In this section, environments in which the beacon collision problem is susceptible to occur are described. These environments can be divided into two categories in terms of the location of the coordinators: direct and indirect beacon frame collisions.

1.1. Direct beacon frame collision

Direct beacon frame collisions occur when two or more coordinators are in the transmission range of each other (direct neighbors or parent-to-child relation) and send their beacon frames at approximately the same time, as shown

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in Fig. 2.

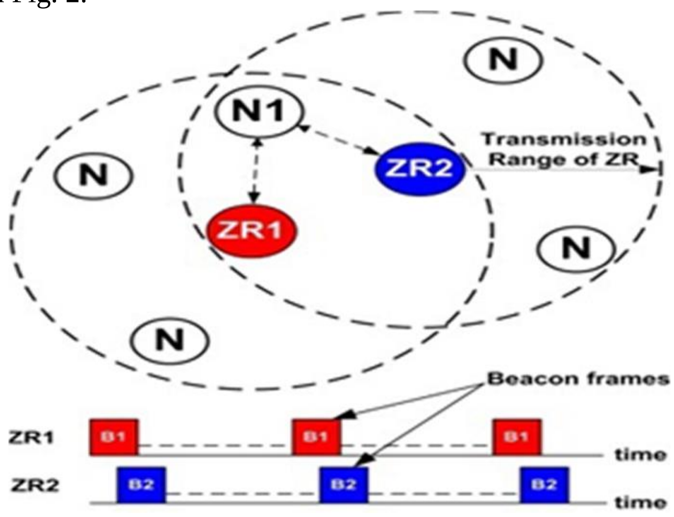

Fig. 2. Direct beacon frame collision

Assume that node N1 is associated with ZR1 and ZR2 is another coordinator. In this case, if ZR1 and ZR2 transmit their beacon frames at approximately the same time, node N1 may lose the beacon information due to the collision of the two beacons. If the superframe duration (SO) of the two coordinators is the same, their beacons will be continuously in conflict with each other [5]. Unfortunately, these two coordinators will not be aware of the collisions.

1.2. Indirect beacon frame collision

In contrast to direct beacon collisions, indirect beacon frame collisions occur when two or more coordinators cannot hear each other, but have overlapped transmission ranges (indirect neighbors) and transmit their beacon frames at approximately the same time, as shown in Fig. 3.

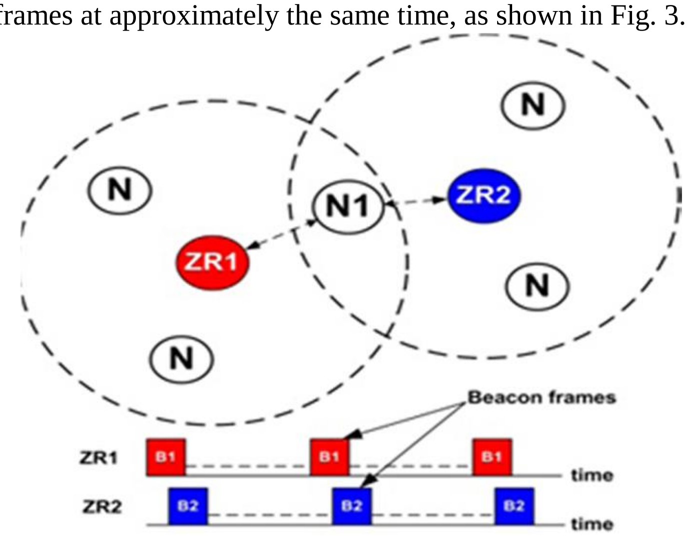

Fig. 3. Indirect beacon frame collision

Assume that node N1, which is located in the overlapped region of the transmission ranges of ZR1 and ZR2, will not be able to correctly receive the beacon frames from either coordinator, since the beacons will collide with each other.

3. BEACON COLLISION AVOIDANCE

Since no mechanism to avoid beacon frame collisions is considered in the current IEEE 802.15.4 standard, some

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proposals have been discussed in Task Group 15.4b. These approaches were proposed as pattern ideas to trigger the design of solutions to the beacon frame collision problem. Two approaches were proposed to avoid this kind of problems, the reactive and proactive ones. As we have said before, the reactive approach does not carry any specific procedure to avoid indirect beacon frame collision beside of the longer time used in the recovery operation of the collided beacon frame [3]. For this raison we focus in this section on the proactive approaches proposed by the Task Group 15.4b which divided into two approaches.

The first approach is the time division, in which, the time is divided such that beacon frames and the superframe duration of a given coordinator are scheduled during the inactive period of its neighbor coordinators, as shown in Fig. 4.

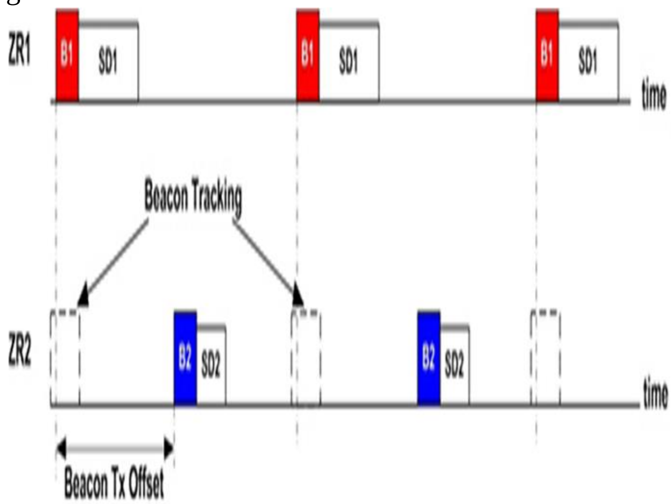

Fig. 4. Time division approach

The idea is that each coordinator uses a starting time Beacon_Tx_Offset to transmit its beacon frames, which must be different from the starting times of its neighbor coordinators and their parents. This approach requires that a coordinator wakes up both in its active period and in its parent's active period. Observe that Beacon_Tx_Offset must be chosen adequately, not only to avoid beacon frame collisions, but also to enable efficient utilization of inactive periods, thus maximizing the number of clusters in the same network. This problem is more challenging when the superframe orders and beacon orders are different from one cluster to another.

In [4], the authors proposed a collision-free superframe duration scheduling (SDS) algorithm, which efficiently organizes the superframe durations of different coordinators in a non-overlapping manner, based on their superframe orders and beacon orders. This algorithm returns "not schedulable" if a given superframe duration cannot find periodic free time slots in the major cycle, otherwise the set is considered as schedulable [5], [6].

The second approach is the beacon-only period. In this approach, a time window, denoted as Beacon-Only Period, is reserved at the beginning of each superframe for the transmission of beacon frames in a contention-free fashion (Fig. 5).

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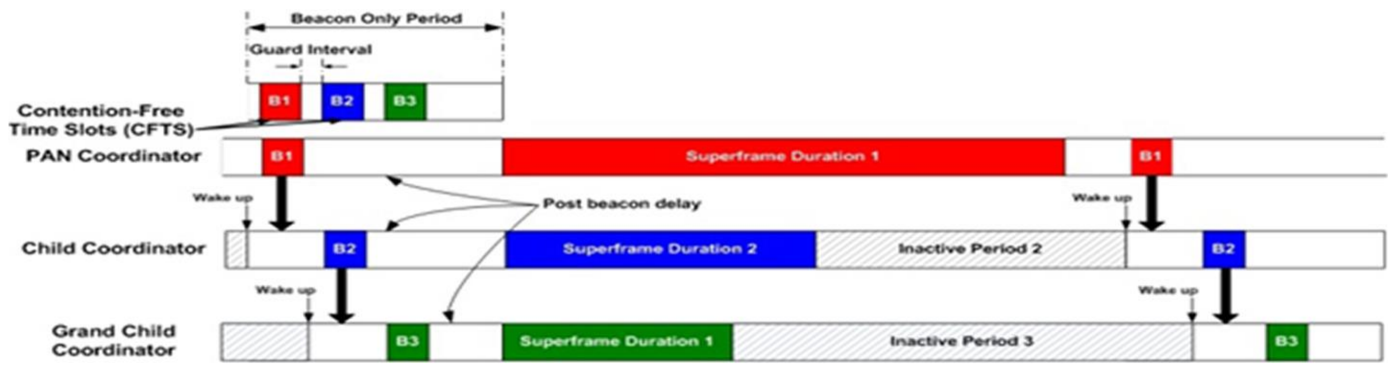

Fig. 5. Boacon only approach

Each coordinator chooses a sending time offset by selecting a contention-free time slot (CFTS) such that its beacon frame does not collide with beacon frames sent by its neighbors. The advantage of this approach as compared to the previous one is that the active periods of the different clusters start at the same time, thus direct communication between neighbor nodes is possible, and there is no constraint on the duty-cycle.

The main complexity of this approach is the dimensioning of the duration of the beacon-only period for a given network topology. This duration depends on the number of nodes in the network, their parent-child relationship and also the scheduling mechanism used to allocate the CFTS (Contention Free Time Slot) to each coordinator.

In [7], the authors proposed an optimized beacon-only period scheduling mechanism for the beacon frames. This proposed solution used to minimize the scheduling period by the allocation of shared CFTSs between the coordinators that doesn't concerned by the following three rules:

--Rule1: Coordinator CFTS should be different from its neighbor CFTS, thus its parent's.

--Rule2: Coordinator Ri CFTS must be different from the CFTS of its neighbor parent.

--Rule3: given a CFTS set organized in an increasing order from index 0 to n-1, coordinator Ri CFTS index will not be higher than the one given to its parent.

Additionally, they proposed the CFGTS notion (Contention Free GTS) which allows the star coordinators to use a GTS in their CFP section with collision avoidance in shared manner, since GTS frames transmission from nodes belonging to different clusters may collide. The following two rules must be respected:

--Rule1: The CFGTS of the couple of nodes Pi/Di should be different from the neighbors' CFGTSs.

--Rule2: The CFGTS of the couple of nodes Pi/Di should be different from the neighbors' parents CFGTSs.

It is important to notice that a GTS is used by the star coordinator and one of its descendants. So, the CFGTS reservation depends on two nodes: the parent Pi and the descendant Di.

In addition, to overcome the limited channel availability of IEEE 802.15.4 LR-WPANs, the authors in [8] proposed the Virtual Channel, a new concept to increase the number of available channels when various WPAN applications coexist. A virtual channel is basically created via superframe scheduling within the inactive periods in a logical channel preoccupied by other WPANs. To maximize the coexistence capability of WPANs using virtual channels, they propose the Least Collision superframe scheduler (LC-scheduler), less complex heuristics, and the Virtual Channel Selector to efficiently manage the multiple available logical channels.

4. MULTI-CHANNEL COMMUNICATION IN WSNs

In order to design good protocol, we need to better understand multi-channel realities in WSNs. A large number of protocols have been proposed for the MAC, routing and transport layers. However with a single channel, WSNs cannot provide reliable and timely communication with high data rate requirements because of radio collisions and limited bandwidth. For example, in the "Ears on the ground" project [1], the network cannot transmit multiple acoustic streams to the sink. On the other hand, a considerable number of multi-channel protocols have been proposed for WSNs in general, such as multi-channel MAC protocols [9], [10], [11] and [12]. These protocols either require multiple radio transceivers at each node, or need certain kinds of control messages for channel negotiation.

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However, they are not suitable for WSN applications. First, each sensor device is usually equipped with a single radio transceiver, which cannot function on different frequencies simultaneously. Second, the network bandwidth in WSNs is very limited and the data packet size is very small. Therefore, channel negotiation packets cannot be ignored as small overhead.

Recently some MAC layer multi-channel protocols have been proposed to improve network performance in WSNs. These protocols typically design sophisticated MAC schemes to coordinate channel switching and transmissions among nodes with considering of the WSN characteristics mentioned above. Simulation results show that they can significantly improve network throughput over MAC protocols using a single channel. Several criteria exist for the classification of these protocols. We can classify them according to the schemes of coordination between channels, the objective of multi-channel using, the channel assignment strategies…etc. we have chosen the channel assignment strategies as criteria in order to know the strategies that can be supported by the protocol IEEE 802.15.4. In the following, we survey the channel assignment strategies in WSNs:

5. Dynamic Channel Assignment

Y-mac [13] is the first example that uses dynamic channel assignment in WSNs. A combination of a dedicated control channel and a frequency hopping method is used. In [14], Voigt extends the D-MAC protocol [15] and proposes to use multi-channel communication to reduce interference problems.

a. Semi-Dynamic Channel Assignment

In semi-dynamic approaches nodes are assigned fixed channels but they can switch between channels in order to communicate with other nodes. Examples are presented in [16], [17], [18], [19], [20], [21] and [22].

b. Fixed Channel Assignment

In this method, the nodes are clustered into different frequencies and the sink can switch between the channels synchronously as in [23], [24] and [25], or simultaneously with using of multi-radios sink as the protocol TMCP in [26], since the sink usually have unlimited energy source. In this latest protocol, it is argued that very frequent channel switching may cause potential packet losses. However, once channel switching is done synchronously, as in semi-dynamic and dynamic channel assignment methods, they face practical issues in real WSNs, including:

1) A large number of orthogonal channels are needed for channel assignment in dense networks.
2) They require precise time synchronization at nodes.
3) Channel switching delay and scheduling overhead cannot be ignored because of frequent channel switching, especially for high data rate traffic.
4) These protocols are typically complex, which require more resources at motes.

In the other hand, the IEEE 802.15.4 standard also uses fixed channel assignment after the scan operation of all the possible frequencies made by the node in the beginning of its starting in order to research the permanent joining channel through its beacon frame. But it is possible that the beacon node can change the operating frequency of its network for at least a superframe period after a negotiation with its parent [2], which makes very difficult the using of a synchronous channel switching scheme even for the sink only in the protocol IEEE802.15.4. For this raison, our scheme considers the using of a multi-radios sink and it focuses on how to use multi-channels to construct the optimal topology with collision avoidance in IEEE802.15.4 protocol.

6. MULTI-CHANNEL SCHEDULING PROTOCOL

In this section, a new beacon collision avoidance algorithm is introduced. The proposed algorithm utilizes the opportunity of multiple channels exist in the protocol IEEE802.15.4 to assign them through a fixe manner, supposing the existence of a multi-radios PAN coordinator. This assignment devises the whole network into multiple disjoint sub networks through an optimal manner. Each sub network use an independent channel in order to avoid the inter sub networks beacon frame collisions. Also, nods on the same channel can be scheduled by using the optimized Beacon-Only approach proposed by the authors of [7] in order to avoid the intra sub network beacon frame collisions. Therefore, this new concept which is a proactive multi-channel method is called the MCSP (Multi-Channel Scheduling Protocol).

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a. Basic Idea

Beacon collisions are fundamentally caused by the limited number of available channels. Even though [4], [7] and[8] tried to efficiently avoid collisions using a proactive method, which is more efficient then the reactive one as it is explained before, this propositions bases on the existence of only one channel which make them suffer again of the beacon collisions specially when the number of nodes increase (more then 7 nodes in [7]). On the other hand, multi-channel solutions depending on fully fixe channels assignment strategy succeed in the avoidance of inter sub networks beacon frame collisions with using of a small number of channels such as TMCP in [26] that seems the more adaptable for the protocol IEEE802.15.4. But it didn't give a solution about the intra sub networks beacon collisions. Therefore, to overcome the limitations of these solutions, we have proposed our method MCSP that combines the advantages of the two sides.

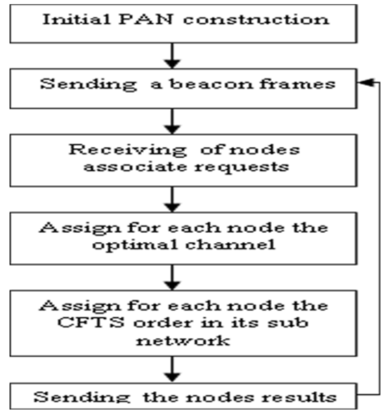

Fig. 6. Flow chart of PAN coordinator using MCSP

Begin
Input: sub network list SL, the root *CP*, for each node U*:* its nature *N* and the set V_u of FFD neighbors with 1 hop;

Output: for each node *U*: *optimal channel* C_u*, the parent* P_u *,* $CFTS_u$ order and $CFTS_p$order ;

For channel i **do**
Insert(SR_i *, CP,null,1)*;
End for

Sort (Node_ liste) in descending order by the number of neighbors then organise FFDs before RFDs according to the nature *N*;

For each node *U* within Node-liste **do**
$C_u = 0$; $P_u = null$; $CFTS_u$=0;
Find optimal sub network SN (SL,U,LFC,Cu,Pu,CFTSp);
Find optimal CFTS (SL(Cu),LFC,Pu,CFTSp,CFTSu);
Insert (SL(Cu), U, Pu,CFu);
Transmit (U,Cu, Pu,CFTSu,CFTSp);
End for
End

Fig. 7. MCSP algorithm for channel assignment and CFTS management

b. MCSP Operation

Based on the above considerations, a new proactive multi-channel method combining the fix channel assignment inspired from the TMCP strategy [26] and the optimized Beacon-Only approach proposed by the authors of [7] is proposed, basically, to maximize the beacon frame collisions avoidance in the protocol IEEE802.15.4. The idea of using multi-channel is to firstly partition the whole network into multiple disjoint sub networks all rooted at the base station and allocate different channels to each sub network, and then forward each flow only along its corresponding sub network. The superiority of MCSP is two-fold. First, for performance concerns, because it assigns different channels among sub networks, it can increase network throughput and eliminate inter and intra-sub networks collisions and exploiting spatial reuses of parallel transmissions among sub networks. Secondly, for practical concerns, with the fact that MCSP requires much fewer channels and it does not need a sophisticated channel coordination scheme, which implies that MCSP supports the specificity of the IEEE802.15.4 standard by the fact that it can work without the need for time synchronization between the channels. For more detailed explanation, the new design of fig. 6 should be followed:

At the initial stage, the PAN coordinator performs an active scan to select a PAN identifier prior to starting a new PAN. Then, it performs an ED scan to detect and save the set of available channels, and then among all channels, it selected the non-adjacent channels according to the number of the exist radios. After that, the PAN coordinator starts the beacon sending through the different radios.

After receiving the beacon frame, the nodes transmit an association requests to the PAN coordinator in order to be allowed to join the network. The PAN coordinator executes the MCSP algorithm (Fig7) to assign for each node the optimal channel (sub network) with its node parent and the CFTS order with its parent CFTS in this sub network.

MCSP begin by the fact of researching for each node the sub network that share the least number of coordinator neighbors (FFD) with the node. This number must be superior then 0 in order to ensure the connectivity. The first

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shared FFD node will selected as the node parent. If more than one sub network, MCSP select those that have a parent with the least number of FFD neighbors in order to avoid as much as possible the beacon frame collisions. If more than one sub network, MCSP select those that have the least size in order to construct a balanced sub networks as much as possible because this interest does not represent our first purpose. If more than one sub network, the choice is optional. The goal of this partitioning is to decrease potential beacon frame collisions as much as possible. We can see that after partitioning, interferences in the original network can be divided into two categories, one is the collisions among different sub networks (inter sub network collisions) which can be eliminated by the above channel assignment, and the other is the potential collisions among nodes within the same sub network (intra sub network collisions). This kind of beacon frame collisions can be avoided in our scheme by the allocation of CFTS order for each node with the following manner:

MCSP mark the variable CFTS with the value 0 if the node is not a coordinator (RFD). However, if the node is an FFD, it takes the value of its CFTS parent then it checks whether this value is different from the other neighboring nodes CFTS values as well as the parent neighboring nodes CFTS values in common with the sub network. If the value exists, MCSP increment it and then resumed the audit until the obtaining of nonexistent value. With this manner, we ensure the beacon frame collisions avoidance within each sub network by an optimal CFTS management applying the three rules mentioned above.

Finally the PAN coordinator transmits the results that combine the channel, the parent, the CFTS order and the parent CFTS order (CFTSp) to the node. The node in turn, switches to the new channel and begin to transmit its own beacon frames in the order received if it is a coordinator node (FFD) by calculation the required time using the formula (1):

$$(CFTSu - CFTSp) \times PR \quad (1)$$

PR represents the time in second to receive a physical packet with maximum size using a flow db.

$$PR = \frac{aMaxPHYPacketSize \times 8}{db} \quad (2)$$

Each node calculates the end of Beacon only period (BP) after the reception of the parent beacon frame, using the equation (3):

$$BP = ((CFTS\max + 1) - CFTSu) \times PR \quad (3)$$

The node found the $CFTS_{max}$ value within each beacon frame updated by the PAN coordinator. This period must always maintain the minimum period of CAP section. For this the PAN coordinator must verify the validity of $CFTS_u$ using (4):

$$CFTSu \leq \left(\frac{(SD - aMinCAPLength) \times DS}{PR} \right) - 1 \quad (4)$$

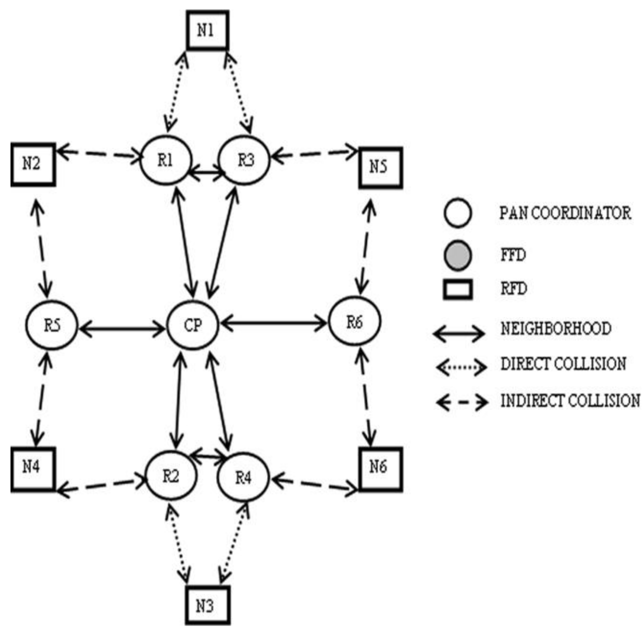

Fig. 8. Experimental model

SD represents the Superframe Duration defined in the standard by (5) [2]:

$$SD = (aBaseSuperframeDuration \times 2^{SO})[symbols] \quad (5)$$

and DS represents the symbol duration.

7. PERFORMANCE EVALUATION

The proposed scheme through simulation is evaluated. The NS-2 version 2.33 including IEEE 802.15.4 simulator developed at the joint simulation Lab of Samsung and the City University of New York is used. The simulator for MCSP based on the MAC layer of 802.15.4 simulator is developed.

To create the environment in which the two kind of beacon collision occurs, the environment showed in Fig. 8 is deployed.

The distance between each FFD and the PAN coordinator must be the same as well as the distance between each RFD and its two neighboring FFDs. We fix an initial backoff time before transmitting the first beacon frame. The common simulation parameters are summarized in Table 1.

TABLE 1
SIMULATION PARAMETERS

PARAMETERS	Value
Channel nbr	1ou2
BO	4
SO	1,3
Transmission range	15m
Node initial energy	1J
E_{elec}	60nj/b
εfs	10nj/b

In the simulation, the beacon order is equal to 4 and the superframe order is varied between 1 and 3. The PAN coordinator starts its operation at 0.0 second. Each of the other nodes start its operation 0.5 second later fro; its previous node respecting the following order: (PAN, R1, N1, N2, R2, N3, N4, R3, N5, R4, N6, R5, then R6.). The simulations are run for 1000 seconds.

Our scheme is implemented in the procedure

"SSCS802_15_4.startDevice" of the MAC sub layer to be executed by the node before transmitting the association request (Association Request). To ensure an accurate simulation, we implement a class accessible by all nodes called TableVoisins to manage the distribution of nodes between the exits sub networks. The nodes use this class to share the parameters of channel, father and CFTS order as well as the neighbor lists between them in order to tqke it in account in the sub networks construction process. This technique has come to address the shortfall that exists in the IEEE802.15.4 protocol implementation in NS, in which a node can be associated with only its parent and not with the PAN coordinator as is specified in the standard. When a node wants to join the network, it makes the scan procedure (Scan Request) and then stores the list of its neighboring coordinators in table of neighbors (Neighbor) included in TableVoisins class, then it run the MCSP algorithm and it stores the different parameters in their corresponding tables then sends an association request (Association Request) to its parent. The latter checks if it accepts or not. If the parent accepts the association it sends an Association Response to the node. When the node receives the response message, it began using its own variables in receiving and transmitting beacon frames, otherwise it deletes the parameters (Fig. 9).

The node is considered as dead when it doesn't receive aMaxLostBeacons beacon frames. This variable is fixed in the standard by the value 4 [2].

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To evaluate the performance of MCSP, 4 variant protocols are used in comparison:

1) The classical IEEE802.15.4 protocol.
2) Uni-channel MCSP with CFTS management.
3) MCSP without CFTS management using 2 channels.
4) Complete MCSP with using of 2 channels.

The second protocol is used to represent the optimized beacon only period approach, wherever, the third one is used to perform the main role of TMCP protocol from which we have inspired the division operation of the entire network between the exists channels. This choice came because of the absence of TMCP source inside, and in other side, the absence of the IEEE802.15.4 implementation in GLOMOSIM simulator used by TMCP.

To evaluate the consumed energy, the energy model of [27] is applied. Let ETx/RTx energy consumed for transmission/reception of a bit, the energy consumed to transmit q bits data over a distance d is equal to:

$$ETx(q,d) = (q \times Elect) + (q \times \varepsilon fs \times d^2) \quad (6)$$

The energy consumed to receive q bits is equal to:

$$Erx(q) = q \times Elect \quad (7)$$

Eelect is the energy consumed by the electronic circuits, εfs is the energy lost in transmission space.

Fig.10 depicts the sum of living nodes with respect to time in the 4 protocols. The original IEEE 802.15.4 doesn't avoid the two types of collisions, the direct collision of N1 then N3 and the indirect collision of N2, N4, N5 and N6 respectively. However, MCSP without CFTS management succeeds in inter sub network beacon frame collisions avoidance, but it doesn't succeeds concerning the intra sub network collisions within each sub network represented by the node N2 between the two coordinator R1 and R5 in the first sub network then the one of the node N5 between the two coordinators R3 and R6 in the second sub network.

The two other protocols are succeed in the save process of all the nodes from the two kind of collisions avoidance with using of 1 channel as well as two channels if the superframe order (SO) was equal to 3 which means that there is a sufficient beacon only period to schedule all the nodes in both cases. However, if SO equal to 1, the beacon only period covered all the nodes only with using of two channels (from 8 nodes with uni channel to 12 nodes with two channels) by the fact of minimizing the scheduled node from 12, in MCSP with 1 channel, to 6 nodes in MCSP with 2 channels which means that the use of only two channels increase the accepted node in scheduling operation by 50%.

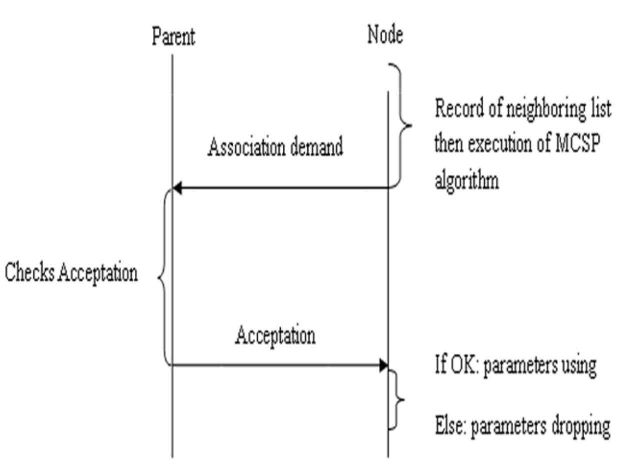

Fig. 9. MCSP algorithm implimentation mechanism

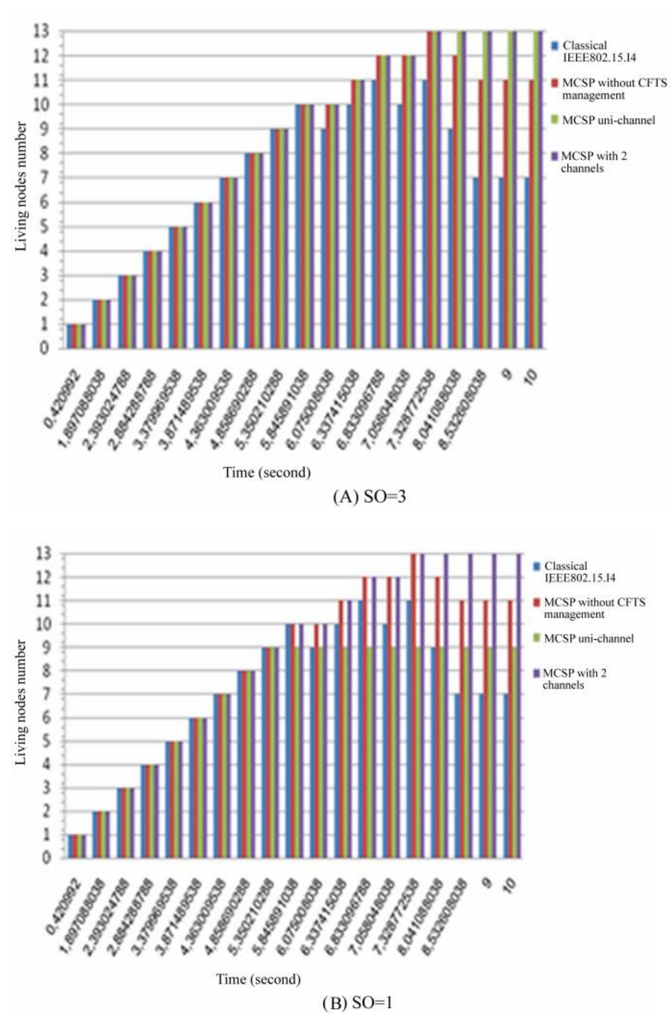

Fig. 10. Number of living nodes

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In Fig. 11, the energy consumption average versus the 200 first seconds is presented. In order to cover all the nodes in both MCSP uni-channel and MCSP multi-channels, the superframe order (SO) is fixed by the value 3. In this simulation, the second protocol consume less energy than the first because of the less number of hearing packets after the channel assignment process made by the PAN coordinator if we don't take the energy consumed by this later in consideration. However, if this energy is taken in consideration, MCSP multi-channels consume more energy than MCSP uni-channel because of the beacon frames duplication operation in transmission made by the PAN coordinator in MCSP multi-channels.

8. CONCLUSION

In this paper, we study how to efficiently use multiple channels to improve beacon frame collisions avoidance in IEEE802.15.4 protocol for WSNs. First, we study collision avoidance approaches in IEEE802.15.4 through a set of related works. It is shown that the proactive beacon only period approach is more suitable for real WSNs because of its direct communication possibility without constraints, but it remains suffer of the small number of nodes that can be accepted in the beacon only period. In light of this observation, we propose the use of multiple channels in order to improve this number by the fact of partitioning the set of nodes on several channels. For this, we study multi-channel realities in WSNs to know the adaptable strategies for the protocol IEEE802.15.4 characterized by the small number of available channels and insupportable time synchronization between channels. It is shown that TMCP fixe channels assignment strategy seems the most adaptable for the protocol IEEE802.15.4 by the fact of taking in account the two above characteristics. As a result of these studies, we propose a multi-channel scheduling protocol MCSP that combine TMCP fixe channel assignment strategy with the optimized proactive beacon only period approach to avoid the beacon frame collisions, but also to improve the number of accepted nodes in IEEE802.15.4 WSNs. Finally, we implement MCSP to evaluate its performance through simulations. Results show that MCSP can greatly improve the beacon frame collisions operation and increase the rate of accepted nodes until 50% using a small number of channels (just two channels in our experimental model), but also it consume less energy than the uni channel protocols with beacon collisions avoidance if we doesn’t take in account the energy consumed by the PAN coordinator supposing that it have an unlimited energy source.

In the future, we plan to extend MCSP to consider the schedule of GTS frames that remains threaten by the two kinds of collisions. We want to develop a CFGTSs management mechanism using multiple channels. This extension can make MCSP more powerful against collision avoidance.

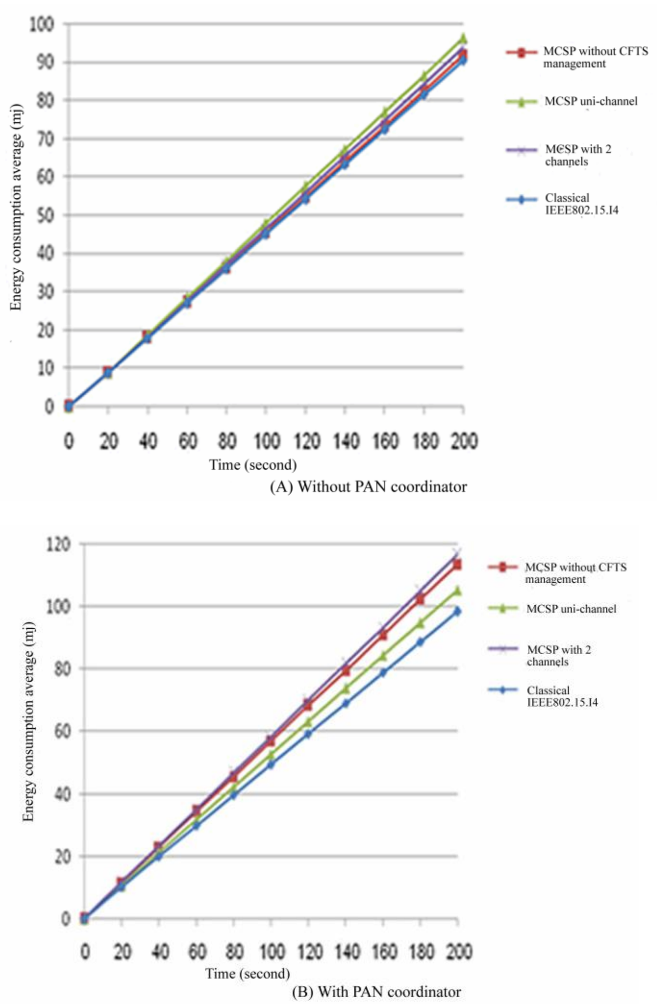

Fig. 11 Energy consumption average

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