A Beacon Cluster-Tree Construction Approach For ZigBee/IEEE802.15.4 Networks

Mohammed.I. Benakila, Laurent George
LACSC Laboratory
ECE Paris, school of engineering
Paris, France
e-mail: Benakila@ece.fr, lgeorge@ieee.org

Smain Femmam
Academy of Strasbourg
University of Haute Alsace
France
e-mail: femmam@ieee.org

***Abstract*— Wireless Sensor Networks (WSN) based on the IEEE 802.15.4 standard are in a constant expansion. Applications like production control, building control are more and more based on WSN because of their energy efficiency, self organization capacity and protocol flexibility. The IEEE 802.15.4 standard defines 3 network topologies: the mesh topology, the star topology and the Cluster-Tree topology. However, the construction of Cluster-Tree networks based on the beacon mode is still undefined by the IEEE 802.15.4 standard. A Beacon Cluster-Tree topology has the advantage of giving all the benefits of the Beacon mode (Synchronization, QoS support through Guaranteed Time Slots) and at the same time, allows the construction of large networks to cover large areas. In order to offer to network architects more flexibility in designing WSN, we present, in this paper, a Beacon Cluster-Tree topology construction approach. Our approach is different from what was proposed until now. We summarize our contribution in three points: (1) there are no conditions on the Beacon mode SuperFrame structure, (2) despite the size of the networks, the construction of a beacon Cluster-Tree topology is always possible and (3) no scheduling is done on SuperFrames or even on Beacon frames transmissions. Indeed, in this paper, we present a novel approach that exploits wireless receivers capability in dealing with multipath to retrieve transmitted data in order to avoid scheduling problems.**

Keywords - IEEE 802.15.4; Beacon mode; Beacon frame ; scheduling; SuperFrame scheduling; Cluster-Tree.

I. INTRODUCTION

Nowadays, the need of controlling human environment is strongly present in people's mind. This need aims at introducing more comfort in people's life, assuring an ambient assisted living (AAL), building automation or factory automation. Such diversified applications require communicating nodes that ensure an efficient data processing, limited energy consumption and must be based on a flexible protocol stack to fit with the requirements of each application.

ZigBee is considered to be a suitable network for sensing and control applications. ZigBee standard defined by the ZigBee Alliance [1] is a communication protocol for Wireless Sensor Networks (WSN). It provides mechanisms for network establishment, device communication and packets routing. Networks implementing this standard are low energy consumption and self-organized. The ZigBee standard is based on the IEEE 802.15.4 standard for the medium access control (MAC sub-layer) and for wireless transmissions and receptions (physical layer).

The IEEE 802.15.4 MAC sub-layer allows two modes for transmitting and receiving data: beacon enabled mode and non-beacon enabled mode [2]. The former can guarantee transmission determinism within Guaranteed Time Slots (GTSs), but needs a synchronization between all the devices forming the beacon enabled network. Non-beacon mode does not give any traffic guarantee and does not need synchronization between devices (see Section 3).

Three topologies are available in the IEEE 802.15.4: mesh topology, star topology and Cluster-Tree topology (see Section 3). The beacon mode has been designed to work with a star topology. However, no mechanisms have been defined in the IEEE 802.15.4 standard to enable the beacon mode using a Mesh or a Cluster-Tree topology. In this paper, we are interested in the construction of a Beacon Cluster-Tree topology, i.e., constructing a Cluster-Tree topology using the beacon mode.

In the present paper, Cluster-Tree mechanisms will not be modified, i.e., no modifications will be made on the association mechanism or data transmission mechanism. All the network devices will transmit during the same SuperFrame, which means that the beacon order (BO) and the SuperFrame order (SO) parameters will be the same for the whole network [2]. Nevertheless, using our approach, SuperFrames scheduling will be avoided and the construction of a Beacon Cluster-Tree network will be always possible without introducing any constraints on the SuperFrames parameters.

The rest of the paper is organized as follows: the next section presents some related works. Section three contains a brief overview of the IEEE 802.15.4 MAC sub-layer. Section four introduces the beacon collision problem within a Cluster-Tree topology, and in Section five we present the most known approaches to resolve this problem. The core of the proposed approach is presented in Section six. Simulation results are presented in Section seven, and finally, we conclude.

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II. RELATED WORKS

Sensor networks applications are in importance nowadays. Sensors applications are much diversified, from temperature sensing to health care. In addition, sensor networks are intended to operate in different environments (factories, hospitals, museums) [3]. Consequently, flexibility in sensor networks design becomes a crucial property that standardization organizations are trying to ensure when defining their protocols.

Proposing new functionalities for a given network topology is a way to provide more flexibility for sensor networks design. We have proposed in [4] the definition of a new device, called the beacon-aware device. This device allows beacon and non-beacon networks cohabitation. The beacon-aware devices permits to create a network composed of a mix of beacon and non-beacon devices. The solution presented in [4] guarantees the integrity of the beacon network traffic by introducing a channel access priority mechanism.

Beside the network size and topology, the QoS is an important parameter to take into consideration. Some sensor applications that require a bounded transport delay can use Guaranteed Time Slots (GTSs) mechanism defined by the IEEE 802.15.4 standard within a fully beacon network. In [5], the authors propose a modelling methodology for Cluster-Tree networks in order to compute worst-case end-to-end delay, buffering and bandwidth requirements. This modelling method enables the network designers to create Cluster-Tree networks that fit with their application constraints.

IEEE 802.15.4/ZigBee standard defines the Cluster-Tree topology as a special case of a peer-to-peer network. But the realization of beacon Cluster-Tree networks is not defined in the standard. Some works have been done in order to model Cluster-Tree topologies [6] [7], failure recovery [8] and to allow the construction of Beacon Cluster-Tree networks.

The RFC submitted to the Task Group 15.4b (see [9]) propose enhancements to the IEEE 802.15.4 standard. The construction of beacon Cluster-Tree topologies was one of the document topics. The authors of [9] classify beacon frames conflicts into two categories: direct conflict and indirect conflict, and propose some approaches to solve each category of beacon conflict.

We present the beacon conflict categories and the approaches proposed by [9] in Section 4.

In [10], Koubaa, Cunha and Alves propose a SuperFrame scheduling algorithm to enhance the approach introduced in [9]. Indeed, the authors of [9] do not introduce any scheduling algorithm. [10] tackles the problem by introducing the constraints and the algorithm needed to provide a strong scheduling mechanism. [11] propose a mechanism to schedule beacon frames transmissions called beacon-only period approach. In this approach, there is no need to schedule SuperFrames, i.e., all the SuperFrames start at the same time. Only beacon frames transmissions are scheduled within a new SuperFrame period called the beacon-only period (for more details, see Section 4 of this paper). In addition, [11] introduces a GTS collision avoidance mechanism which guarantees a certain traffic QoS.

In this paper, we present and discuss the drawbacks of those solutions for the Cluster-Tree network management in Sections 4 and 5. We then describe the approach we propose in Section 6.

III. IEEE 802.15.4 MAC SUB-LAYER OVERVIEW

The IEEE 802.15.4 standard is a suitable protocol for low rate wireless networks. A lot of efforts has been done to make the standard low-power and self organized.

Tow kinds of devices have been introduced in [2], reduced function devices (RFD) and full function devices (FFD). A FFD is a device that implements all the functions defined by the standard. However, a RFD implements the basic functions (join a network, leave a network, transmit, etc.) defined in the standard. Two topologies are allowed by the standard:

Mesh topology:

In a mesh topology, there is one coordinator and a set of nodes associated to it. Each node is a router and permits other nodes association. A given node can communicate directly with other nodes if they are in its POS (Personal Operating Space, i.e., in-range transmission), or, passing by other nodes (acting as routers in this case) to reach its target node (see Figure 1). Using this topology, no synchronization is needed between the devices.

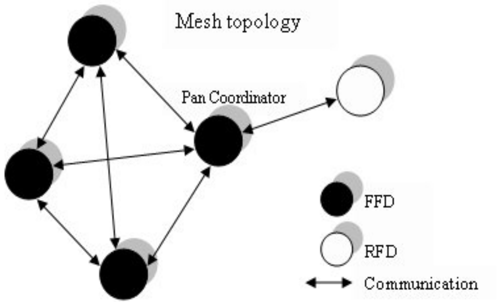


Figure 1. Mesh topology.

Furthermore, enabling the synchronization in such a topology can be problematic since synchronization mechanisms for mesh topology are not defined in the standard.

Star topology:

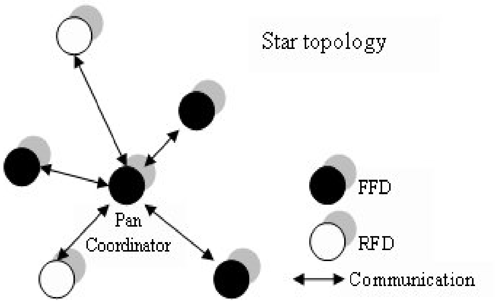


Figure 2. Star topology.

The coordinator is the main node in the network. All other nodes must be associated to it, and all communications between nodes must pass through it, even if the communication initiator node and the target node are in the POS of each other (see Figure 2). Performing synchronization (beacon mode) using this topology has been well defined by the IEEE 802.15.4 standard.

A third topology can be considered also, the Cluster-Tree topology. This topology is not defined in the 2006 version of the standard, but, was defined in the 2003 version of the standard. The Cluster-Tree topology is very interesting for time sensitive applications. Here after, the Cluster-Tree topology is introduced.

Cluster-Tree topology:

A Cluster-Tree network is a network in which most devices are FFDs. A RFD connects to a cluster tree network as a leaf device at the end of a branch (RFDs do not allow other devices to associate). A FFD device may act as a coordinator and provides synchronization services to other devices or other coordinators. The PAN coordinator forms the first cluster by choosing an unused PAN identifier and broadcasting beacon frames to neighboring devices. A candidate device receiving a beacon frame may request to join the network at the PAN coordinator. If the PAN coordinator permits the device to join, it adds the new device as a child device in its neighbor list. Then the newly joined device adds the PAN coordinator as its parent in its neighbor list and begins transmitting periodic beacons; other candidate devices may then join the network at that device. The simplest form of a cluster tree network is a single cluster network, but larger networks are possible by forming a mesh of multiple neighboring clusters. Once predetermined application or network requirements are met, the first PAN coordinator may instruct a device to become the PAN coordinator of a new cluster (Cluster head) adjacent to the first one. Other devices gradually connect and form a multicluster network structure (see Figure 3).

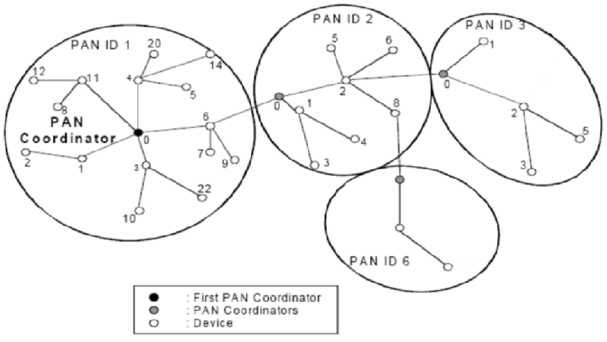


Figure 3. Cluster-Tree topology.

A. Non-beacon enabled network

In a non-beacon mode, the three topologies can be used. This mode assumes that every node can communicate directly with other nodes without any synchronization requirements. A node can transmit at any time, and can go to sleep at any time following its own energy consumption policy. All transmissions are done after performing the unslotted CSMA/CA algorithm to check if the channel is clear for a transmission or not.

A non-beacon device transmits the beacon frame only as a response to a beacon request command. Devices operating in this mode do not need to synchronize with other devices.

B. Beacon enabled network

In a beacon enabled mode, the coordinator plays a crucial role. It defines periods of time in which transmissions can be done and intervals of time where all nodes associated to it must go to sleep.

In this mode, the time is divided into a succession of ”SuperFrames”. A SuperFrame is a time interval that contains an active period and an inactive period. The Beacon Interval (BI) parameter indicates the interval between two successive beacon frames. The length of the active period is indicated by SD (SuperFrame Duration) parameter. The active period is divided into a fixed number of 16 time slots of equal sizes. All beacon network communications are done within this period. The active period is divided into a contention access period (CAP) and a contention free period (CFP).

The CAP is the period where all nodes compete for channel access using the slotted CSMA/CA algorithm.

The CFP gathers GTSs (Guaranteed Time Slots). A GTS is one or more slots of time reserved for a particular node.

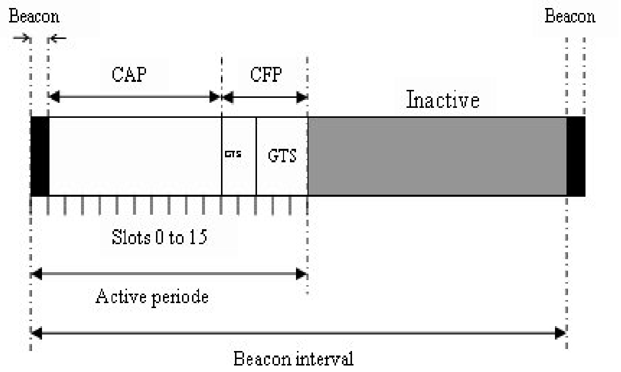


Figure 4. IEEE 802.15.4 SuperFrame structure.

A GTS is unidirectional, i.e., only for receptions or only for transmissions. The coordinator starts allocating GTSs from the last time slot to the first slots respecting a maximum size of the CFP. GTS transmissions do not need the use of CSMA/CA algorithm for channel access since the slots are reserved for one node. The structure of a SuperFrame is illustrated in Figure 4.

Beacon mode forces all the devices to synchronize with the coordinator. This is done by the reception and the process of the beacon frame. The most important parameters for synchronization are: the Beacon Order (BO) which is a parameter for computing BI, the Superframe Order (SO) which is a parameter for computing SD and the final CAP slot parameter. The final CAP slot indicates the end of the CAP. After this slot, only devices owning a GTS can transmit. Figure 5 presents the format of the beacon frame.

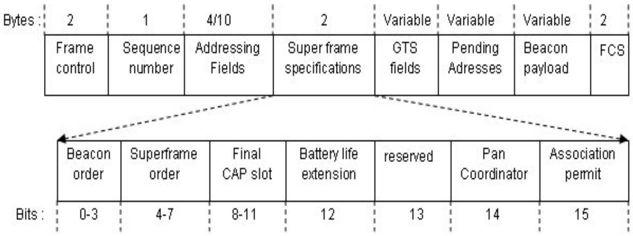


Figure 5. Beacon frame structure.

The BO is a parameter used by the associated nodes for calculating the beacon interval, which is computed using this formula :

$$BI = aBaseSuperFrameDuration * 2^{BO} \qquad (1)$$

with: aBaseSuperFrameDuration = 60 symbols.
The BO value should be between 0 and 14.
A BO with a value of 15 indicates that the device operates in non-beacon mode.
The SO is a parameter used for calculating the active period duration.

$$SD = aBaseSuperFrameDuration * 2^{SO} \qquad (2)$$

with: $0 \leq SO \leq BO \leq 14$.

IV. BEACON FRAME COLLISION IN A CLUSTER-TREE TOPOLOGY

In this section, we present the beacon frame collision problem when a Cluster-Tree topology is considered. This problem has been addressed as a request for comment (RFC) by the Task Group 15.4b in [9].

Two types of beacon frame collision have been identified in [9].

A. *Direct beacon frame collision*

A direct beacon frame collision occurs when more than one coordinator are in the transmission range of each other, and the beacon transmission occurs in approximatively the same time (see Figure 6(a)).

B. *Indirect beacon frame collision*

An indirect beacon frame collision occurs when a given node is in the transmission range of two or more coordinators. The coordinators send their beacon frames at approximatively the same time, i.e., at a given time, the node receives more then one beacon frame which results in the collision. This situation is a typical hide nodes transmission situation (see Figure 6(b)).

For more details about the beacon frame collision problem, see [9].

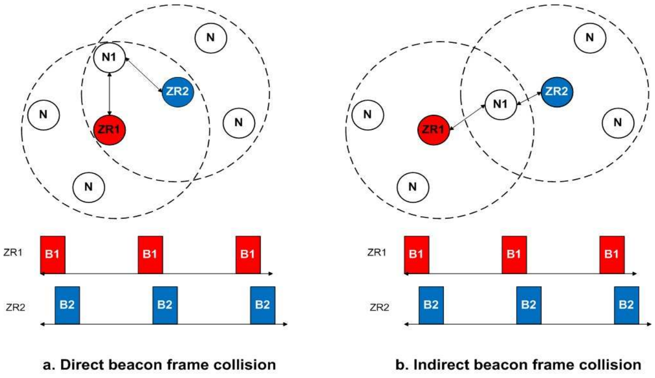


Figure 6. Beacon frame collision situations.

V. BEACON FRAME COLLISION AVOIDANCE USING THE TEMPLATE

This section contains a presentation of beacon frame collision avoidance mechanisms for each of the situations presented in the previous section.

A. *Direct beacon frame collision avoidance*

Two main approaches have been proposed to solve the problem of direct beacon frame collision: the time division approach and the beacon-only period approach. These approaches were defined in [9] and developed in [10] and [11].

The time division approach:

Basically, this approach consists in the following principals:

A given coordinator transmits its beacon frame and spends its active period during the inactive period of its neighbor coordinators. The Task Group 15.4b does not propose any scheduling algorithm in order to increase the mechanism efficiency. This lack has been tackled in [10].

The authors of [10] propose a SuperFrame scheduling algorithm in order to maximize the number of clusters in the network.

This approach suffers from several problems:

- To enable parent/child communications, a coordinator is activated during its active period and during the active period of its parent coordinator.
- The increasing density of devices in the network makes the problem more complicated, and the scheduling algorithm proposed in [10] may return an ”unschedulable set” response, which means that the Cluster-Tree topology can not be used.
- To make the SuperFrame scheduling algorithm more efficient, the authors of [10] have made restrictive constraints on the SO and the BO parameters, which could perturb the execution of some applications in the network.

The beacon-only period approach:

In this approach, the SuperFrame structure is modified. A time period, called ”Beacon-Only period”, is added at the beginning of the SuperFrame. The beacon-only period is divided into time slots called ”Contention-Free Time Slot” (CFTS). Each coordinator transmits its beacon frame within its CFTS (see Figure 7). Thus, beacon frame collisions will be avoided.

This approach has been presented, first, by the Task Group 15.4b, and then it was developed in [10] and [11].

However, dimensioning the beacon-only period is complicated since the duration of the period must be evaluated dynamically depending on association and leaving actions of beacon coordinators. In addition, the beacon-only approach does not avoid indirect beacon frames collision, or it does, but, with including global CFTS scheduling algorithm.

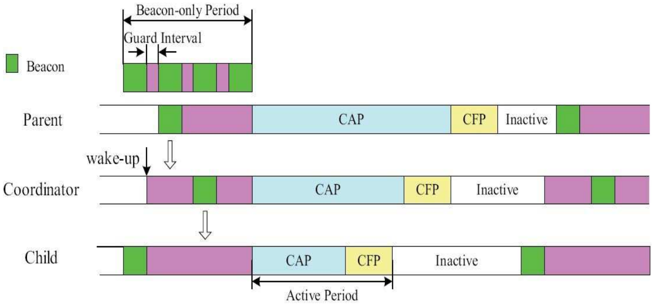


Figure 7. The beacon-only period approach.

B. Indirect beacon frame collision avoidance

Indirect beacon frame collision can be solved by the following two approaches:

The reactive approach:

Enabling this approach, the network is started normally and the coordinators do not do much to prevent from beacon frame collisions. Once a collision occurs, the node (the node in the POS of more than one coordinator, see Figure 6) will start orphan scans to try to re-synchronize with its coordinator. However, if after a number of orphan scans, the node is still unable to receive correctly the beacon frame, it initiates a beacon conflict command. Coordinators receiving the beacon conflict command will adjust their beacon transmission time in order to solve the problem.

This approach is simple, but, the recovery from a beacon conflict can take a long time.

The proactive approach:

In the proactive approach, coordinators try to avoid beacon frames conflict before starting their beacon frames transmission. A coordinator listens to the channel and collects its neighbours beacon frame transmission time. Nevertheless, if a beacon frame collision is reported, the network is able to solve the problem using the reactive approach.

Notice that this approach is more complicated than the first one.

C. Discussion

Previously, we presented different approaches proposed to enable the construction of a beacon Cluster-Tree topology. This section contains a discussion about the presented solutions and our motivations to present a new approach.

The Time Division Beacon Scheduling (TDBS) [10] is an improvement of the solution proposed by the Task Group 15.4b. This approach is based on a scheduling algorithm to avoid beacon collisions. However, the TDBS approach suffers from several lacks (see Section 5.1).

The second approach presented was the beacon-only period approach. This approach suffers also from several lacks presented in Section 5.1.

The approach we present, in the next section, aims at enabling the following properties:

- It’s clear that scheduling algorithms (for SuperFrames or Beacon frames) are inappropriate for networks with high nodes density. Our approach does not introduce any scheduling algorithm which means that the solution presented in this paper can be applied to construct beacon Cluster-Tree networks whatever the size of the network.
- Using our approach (same case for the beacon-only period approach), parent/child communications are easily enabled. In fact, to communicate with its parent node, a given node does not need to be active during its active period and its parent active period. Therefore, this mechanism simplifies the protocol implementation and reduces the energy consumption of the nodes forming the network.

VI. OUR APPROACH

In this section, we propose a new approach that allows forming Cluster-Tree networks without regard to the density of the network. Indeed, our approach is not based on SuperFrames or even Beacon frames transmission scheduling.

In our approach, the Cluster-Tree network is constructed thanks to the following:

- The same BO and SO values for all the nodes of the network [2].
- All the nodes are synchronized thanks to beacon frames transmission.
- All the nodes transmit during the same SuperFrame.

These points are detailed in the rest of this section.

A. *Beacon frame transmission*

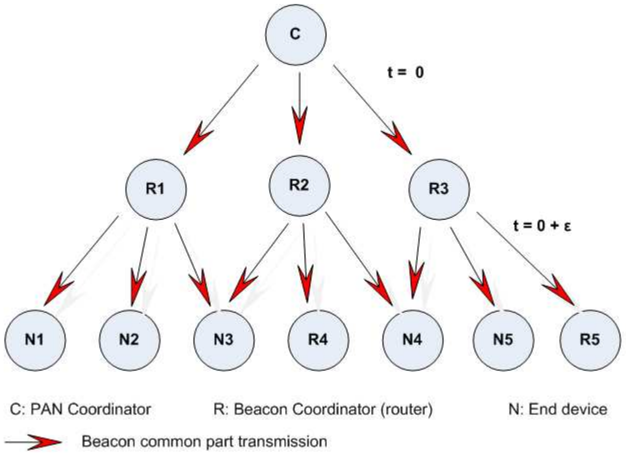


Figure 8. Beacon common part transmission.

To enable collision-free beacon transmissions, we are adopting a novel approach, described in this section. The beacon frame is divided into two parts:

- A common part: It is the part that does not change from a beacon coordinator to another. It contains the SO and the BO parameters.
- A specific part: It is the part specific to a beacon coordinator, i.e., changes from a given beacon coordinator to another.

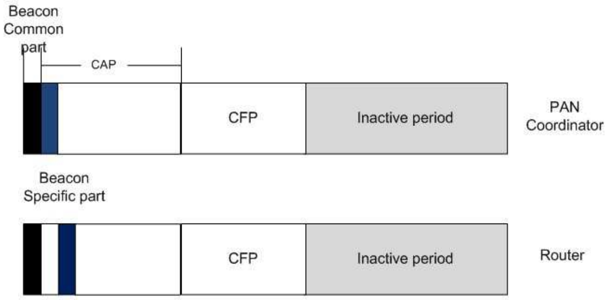


Figure 9. SuperFrame structure.

Each part is a separate frame. The transmission mechanism is described in Figure 8.

Nodes synchronization is achieved by the transmission of the common part. It gives the start signal to sensor nodes to begin the Beacon mode SuperFrame.

The common part contains only synchronization information (BO and SO).

The specific part is transmitted during the CAP period and it contains the traditional beacon information (GTSs, Pending addresses, etc.).

The PAN Coordinator broadcasts the beacon common part.

When the beacon common part is received, a beacon coordinator begins its SuperFrame and forwards the same frame (i.e., the beacon common part) to its neighbour nodes. Using this mechanism, beacon coordinators at the same level of the Cluster-Tree can transmit the common part at the same time. This should not cause a reception problem if a node receives more than one frame at the same time.

Indeed, all the beacon routers are broadcasting the same frame, the same bit configuration which means that all the beacon routers are transmitting the same RF signal. When a node receives more than one RF signal it can extract the message because all the RF signals are considered as multipath RF signals.

Multipath propagation occurs when RF signals take different paths from a source to a destination. A part of the signal goes to the destination while another part bounces off an obstruction, and then arrives to the destination. As a result, a part of the signal encounters delay and travels a longer path to the destination. Multipath can be defined as the combination of the original signal plus the duplicate wave fronts that result from reflection of the waves off obstacles between the transmitter and the receiver [12].

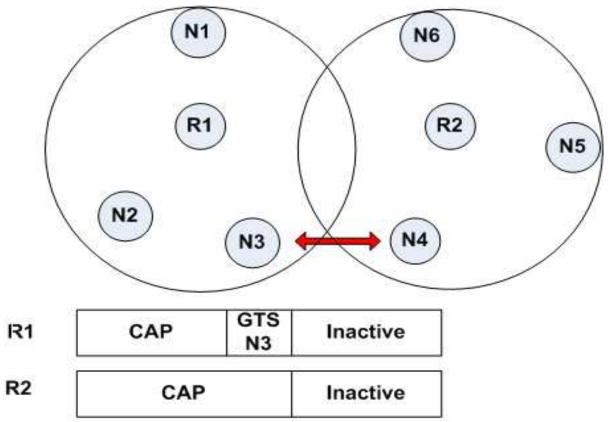


Figure 10. Example of a GTS collision case.

Multipath propagation occurs even with only one transmitter and one receiver. Nowadays receivers are able to retrieve the information from a RF signal perturbed by reflected RF signals.

Thus, a node receiving the beacon common part from more than one beacon coordinator (i.e., more than one RF signal) is able to retrieve the common part information since the node is able to deal with multipath RF signals, as confirmed in the experiments we have done in Section 7.

B. *GTS Allocation*

In our approach, each beacon coordinator manages independently its CFP period. It is able to accept or reject GTS requests and it is responsible for assigning GTS time slots to its children nodes. However, a mechanism must be introduced to avoid GTS transmission disruption by neighbor nodes transmissions. Figure 10 illustrates a case where a GTS transmission can be perturbed. We can see that if node"N4" is transmitting while "N3" is in its GTS period, there will be frame collisions.

To avoid this problem, GTS collision avoidance mechanisms should be implemented. We can conceive proactive or reactive approaches. These approaches are out of the scope of this paper.

Figure 11. MicroChip sniffer (left), PICDEM Z (left).

VII. SIMULATION AND EXPERIMENTS

This section aims at proving the well-functioning of the mechanism.

In the first part of this section we present experimentations we have done to show that receivers' capability to deal with multipaths could be exploited to transmit the beacon common part.

In the second part of this section, NS2 simulations are done to show that our approach can be implemented on sensor nodes.

A. *Multipath exploitation*

The core of our approach is the exploitation of multipath phenomena to avoid beacon transmission scheduling. Indeed, since receivers are able to deal with RF reflected signals to retrieve the information, they can retrieve information from RF signals (same RF signal) transmitted by different nodes at approximately the same time. All these RF signals will be considered as multipath signals by the receiver.

To put the stress upon this point, we conceived a real experimentation using the MicroChip PICDEM Z modules (see Figure 11). The principle is to send the same frame by several nodes to one receiver. For visual considerations, we choose a MicroChip sniffer as a receiver. The network architecture is presented in Figure 12.

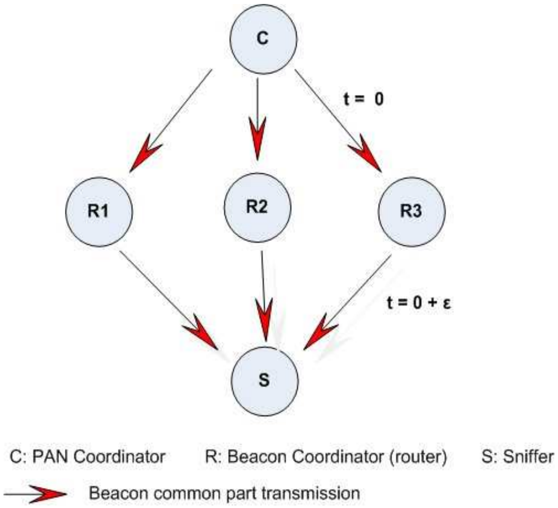
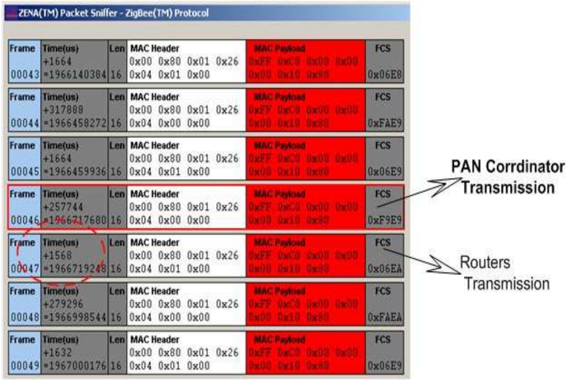


Figure 12. Network architecture for the test.

The receiver is in the transmission range of the PAN Coordinator and the three routers, i.e., the sniffer's software shows two frames which will allow us to measure the time offset between the reception and the transmission of the frame. When a router receives the frame from the PAN Coordinator, it retransmits it immediately. As it is shown in Figure 13, the sniffer receives two frames: the first one is the

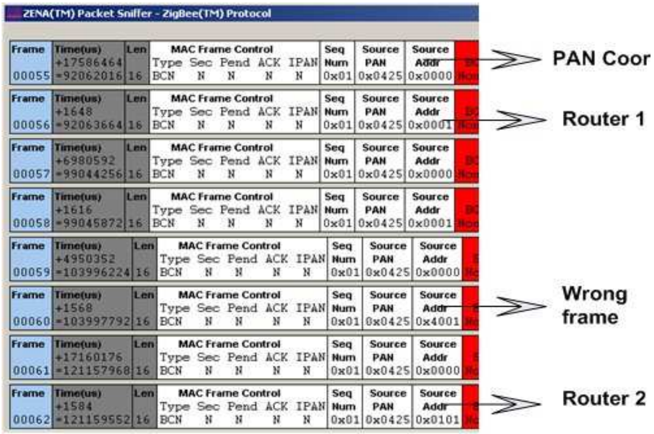


Frame	Time(us)	Len	MAC Header	MAC Payload	FCS
00043	+1664 =1966140384	16	0x00 0x80 0x01 0x26 0x04 0x01 0x00	0xFF 0xC0 0x00 0x00 0x00 0x10 0x80	0x06E8
00044	+317888 =1966458272	16	0x00 0x80 0x01 0x26 0x04 0x00 0x00	0xFF 0xC0 0x00 0x00 0x00 0x10 0x80	0xFAE9
00045	+1664 =1966459936	16	0x00 0x80 0x01 0x26 0x04 0x01 0x00	0xFF 0xC0 0x00 0x00 0x00 0x10 0x80	0x06E9
00046	+257744 =1966717680	16	0x00 0x80 0x01 0x26 0x04 0x00 0x00	0xFF 0xC0 0x00 0x00 0x00 0x10 0x80	0xF9E9
00047	+1568 =1966719248	16	0x00 0x80 0x01 0x26 0x04 0x01 0x00	0xFF 0xC0 0x00 0x00 0x00 0x10 0x80	0x06EA
00048	+279296 =1966998544	16	0x00 0x80 0x01 0x26 0x04 0x00 0x00	0xFF 0xC0 0x00 0x00 0x00 0x10 0x80	0xFAEA
00049	+1632 =1967000176	16	0x00 0x80 0x01 0x26 0x04 0x01 0x00	0xFF 0xC0 0x00 0x00 0x00 0x10 0x80	0x06E9

Figure 13. Frames received by the MicroChip sniffer (same bit configuration).

frame transmitted by the PAN Coordinator and the second one is the frame transmitted by the routers. The sniffer receives only one frame from the routers although there are three transmissions. Consequently, the receiver considers all the transmissions as only one transmission.

This receiver capability in processing multipath avoids introducing beacon or SuperFrames scheduling mechanisms.


ZENA(TM) Packet Sniffer - ZigBee(TM) Protocol

Frame	Time(us)	Len	MAC Frame Control Type	Sec	Pend	ACK	IPAN	Seq Num	Source PAN	Source Addr
00055	+17586464 =92062016	16	BCN	N	N	N	N	0x01	0x0425	0x0000
00056	+1648 =92063664	16	BCN	N	N	N	N	0x01	0x0425	0x0001
00057	+6980592 =99044256	16	BCN	N	N	N	N	0x01	0x0425	0x0000
00058	+1616 =99045872	16	BCN	N	N	N	N	0x01	0x0425	0x0001
00059	+4950352 =103996224	16	BCN	N	N	N	N	0x01	0x0425	0x0000
00060	+1568 =103997792	16	BCN	N	N	N	N	0x01	0x0425	0x4001
00061	+17160176 =121157968	16	BCN	N	N	N	N	0x01	0x0425	0x0000
00062	+1584 =121159552	16	BCN	N	N	N	N	0x01	0x0425	0x0101

Figure 14. Frames received by the MicroChip sniffer (different bit configuration).

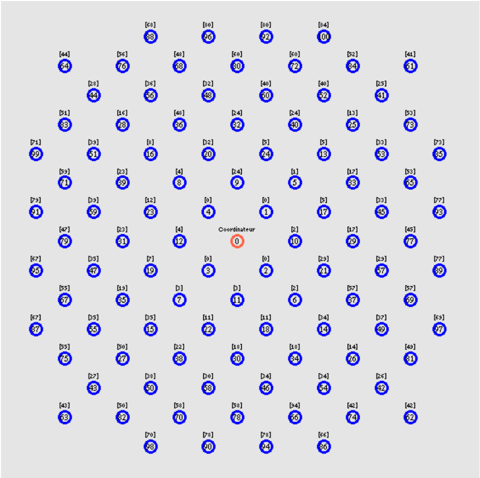


Figure 15. Network topology for NS2 simulation.

To show the impact of receiving different frames by the sniffer, the same network architecture as in Figure 12 is considered. Except, we are using only two routers instead of three. The frame transmitted by each router is different.

Instead of using the same bit configuration, each device (routers and PAN coordinator) in the network uses its 16-bits address. Only the addresses are different, the rest of the frame is the same for both devices.

Figure 14 shows the frames received by the sniffer when the frames are different. The PAN Coordinator's address is 0x0000, router1's address is 0x0001 and router2's address is 0x0101. From Figure 14 we can see that the sniffer receives only one frame instead of two frames. In addition, the received frame could be corrupted. In the figure, the sniffers interprets a received frame as a frame sent by a node with the address 0x4001 which does not exist in the network.

B. Network simulation

In this section, the presented approach is implemented in NS2 simulator. NS2 source code for IEEE 802.15.4 [13] is modified to support the mechanisms presented in this paper. The goal of this section is to show that our approach is implementable on a sensor node. Performances comparison is not presented.

The considered network topology under NS2 is presented in Figure 15. There are 101 nodes and all the devices are routers that accept nodes association.

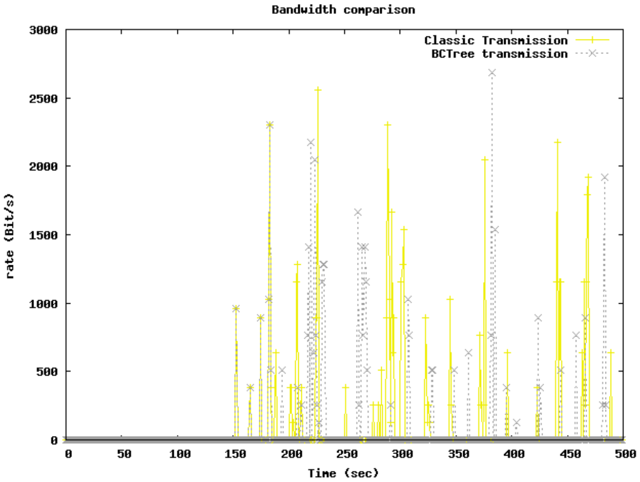


Figure 1. Bandwidth comparison (NS2 implementation vs our approach).

Our approach does not introduce any changes on association mechanisms. During the association, classic beacon frames are transmitted. Once the network is established, the beacon common part is used to give the start signal of the SuperFrame and the specific beacon part is used to send information concerning GTS, Final CAP Slot, pending addresses, etc.

Figures 16 and 17 represent bandwidth measures are represented. Figure 16, shows a comparison between bandwidth for a transmission from node 20 to node 64. It is a FTP over TCP traffic transmitted first using our approach and in a second time using the original implementation of the IEEE 802.15.4 in NS2. Both transmissions starts at t=150 sec and continue until approximately t=500 sec. In this simulation, we used the same BO and SO values in both cases (our approach and IEEE 802.15.4 NS source code). The goal is to validate the changes introduced in the IEEE 802.15.4 NS2 source code.

Figure 17 shows the bandwidth of different traffic flows. Four FTP over TCP flows are considered: node 20 to node 64, node 31 to node 24, node 33 to node 50 and node 80 to node 39.

Thus, from Figures 16 and 17 we can say that the introduced approach does not affect frames transmission mechanism.

VIII. CONCLUSION AND FUTURE WORKS

In this paper, we presented a new approach for the construction of ZigBee/IEEE 802.15.4 Cluster-Tree networks. The presented approach tackles the problems of beacon frames and SuperFrames scheduling. It allows the construction of Cluster-Tree topology without introducing constraints on SuperFrames structure and without taking into account the nodes density in the network.

We proposeed a collision-free beacon transmission approach that exploits node's capabilities in extracting the information from a signal perturbed by simultaneous transmissions of several beacon coordinators. These transmitted RF signals are considered as reflected RF signals since all the beacon coordinators are broadcasting the same signal.

Future works will deal with adapting the presented approach to enable the construction of Beacon mesh networks. For time sensitive applications a GTS collision avoidance mechanism must be introduced to grant the GTS traffic.

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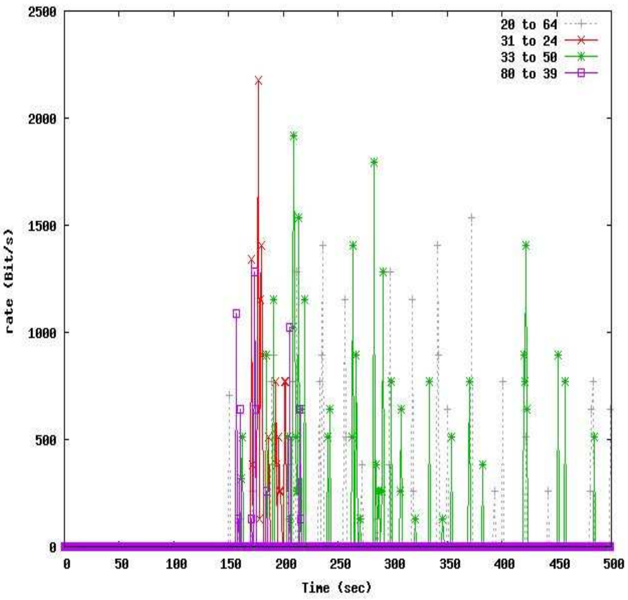

Figure 2. Bandwidth in the case of multiple transmissions.

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