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Enhancement and Performance Evaluation of a Multicast Routing Mechanism in ZigBee Cluster-tree Wireless Sensor networks

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***Abstract*—Routing is a challenging issue in Wireless Sensor Networks *(WSNs)* due to their inherent memory and energy constraints. Multicast Routing is used when dealing with group communication and it is well used in WSNs because it improves efficiency and reduces path length in the network. ZigBee is a standard protocol that presents a very prominent technology for WSNs. Z-Cast is a multicast mechanism that has been proposed for ZigBee cluster-tree WSNs. However, this mechanism was not tested on a real WSN platform and presents some gaps related to its memory and communication. In addition, the performance of this mechanism has not been evaluated. In this paper, we address these problems and present an amelioration of this protocol. In addition, we integrate this mechanism in Open-ZB toolset as this implementation does not consider multicast routing in its specification. The main contributions of this paper are two folded: first, we propose an amelioration of Z-Cast that may improve its efficiency and reduce its memory cost. Second, we integrate this protocol in Open-ZB and evaluate its performance on telosB motes.**

***Index Terms*—Wireless Sensor Networks (WSNs), ZigBee, Cluster-tree network, group communication, multicast routing, Open-ZB, Z-Cast, telosB.**

I. Introduction

First WSNs applications involve communications between two network devices. However, important emerging applications like code updates, task assignment and targeted queries, require simultaneous communication between groups of network devices. Multicast routing protocols can offer several benefits. The use of a set of point-to-point communications to support a virtual multicast environment results in a complex and inefficient process, mainly in large scale networks. When a source needs to transmit a message to n receivers using point-to-point communication mechanisms, it is necessary to transmit the same message n times. In the case of large number of receivers, this technology is unfeasible due to the communication overhead. Thus, the emergence of applications with inherent multicast requirements led to the development of multicast routing protocols.

There have been a lot of research works in the context of ad hoc networks such as [15], [16], [17], [18] and [14]. However, they are not suitable to be applied directly in WSNs as they are designed to be applied with machines with high computation and storage capabilities. There have been a lot of proposals for multicast routing in the context of WSNs such as [19], [20], [21], [6]..

However, these proposals are designed to a specific topology or to a particular application.

The IEEE 802.15.4/ZigBee [2] standard protocol is a low rate short range wireless technology with low cost and low power for end devices. It is considered as an important technology for WSNs [4]. In [1], the authors have proposed a multicast routing protocol that can be applied for ZigBee cluster-tree networks. However, this protocol presents some gaps related to the memory consumption of the nodes and the high communication overhead. In addition, the proposal was not validated by a real implementation.

In this paper, we address these issues and study the important features of this multicast protocol. In addition, we propose amelioration for this protocol and its validation by a real implementation on sensor motes.

Thus, the main contributions of this paper are: (1) the implementation of the multicast routing protocol Z-Cast that has been designed for Zig-Bee cluster-tree WSNs, (2) the proposal of an amelioration so that it consumes lower energy and memory storage and (3) performance evaluation of the resulting mechanism.

The remainder of this paper is organized as follows: In section 2, we present a state of the art of the most important proposals that are related to multicast routing in WSNs. In section 3, we study Z-Cast and present our proposition in ameliorating it. Then, we present our performance evaluation of this mechanism on TelosB motes in section 4. Finally, we conclude with a general conclusion and identify topics for future research work.

II. Related Work

IEEE 802.15.4 standard defines the characteristics of the multicast is an efficient way to disseminate data to a group of receivers that are interested in the same content. Contrary to unicast, where the sender has to transmit the data for each receiver individually, multicast requires the sender to transmit the data only once. Thereafter, the network or other hosts interested in the data will replicate when required and forward the data to the receiving group members.In this context,numerous research has been done about multicast routing in WSNs.

In [5], the authors defined a mobile multicast system for wireless sensor networks. This scheme builds lightweight multicast support characterized by hierarchy and mobility.

The addressing adapted is 8 bit ID for nodes and groups. For routing, this scheme uses unicast to do the Node-to-base station routing and multicast to do the base station-to-node routing. Rather than building multicast on top of an underlying unicast network, it is implemented directly on top of the link layer. This approach significantly reduces router state and code size. However, the implementation is so specific that the scheme cannot be combined with other energy efficient protocols such as data aggregation etc. Moreover, control messages for mobility support and group management are necessary.

In[6], the authors proposed an ad-hoc multicast routing on resssource-limited sensor nodes . This approach is based on the Adaptive Demand-driven Multicast Routing (ADMR) [9]. The forwarding trees are constructed on demand : both the sender and the receiver could initiate route-discovery based on different metrics (hop-count, LQI). The protocol needs 3 tables on each node : Node Table, Membership Table and Sender Table.

In [7], the authors proposed a Geographic Multicast routing Protocol (GMP). It focuses mainly on tree building. In fact, each transmitting node builds Euclidian Steiner Trees. This mechanism is used in each routing step.

In [8], another Geographic Multicast Routing for WSNs is proposed (GMR). This scheme is based on geographic unicast routing protocols. It uses cost-based neighbor selection on each routing step.

In [10], the authors show the mapping of DCMP [11](dynamic core based multicast routing protocol for ad hoc networks) to Zigbee networks. This scheme is compatible with zigbee cluster tree and mesh networks but it has a communication and a memory overhead. Further more, this work is not implemented yet and not evaluated.

In [1], the authors proposed a multicast routing mechanism in ZigBee cluster-Tree wireless sensor networks. This scheme will be detailed more in section 3 of this paper.

In this paper, we have studied the multicast protocols designed for WSNs. We have noticed that most of them have some limits: most of them were not implemented or, in the best cases, they are in a developing stage. In addition, they are application specific. As we are interested in ZigBee standard, we have focused on one research work that has been designed to ZigBee networks [1].

III. Study of Z-Cast and Enhancement

In our work, we are interested in Multicast routing mechanisms for the ZigBee cluster-tree Wireless Sensor Networks to send and receive data between nodes that have the same interest to the sensory information collected by sensor nodes in a ZigBee network. In [1], the authors proposed Z-Cast: A multicast routing mechanism for ZigBee cluster-tree wireless sensor networks. Our main contribution is the real implementation and the integration of the proposed protocol within the open source implementation of the IEEE 802.15.4/ZigBee. Then, we are interested in the amelioration of this protocol so that it requires less memory storage and low message overhead when dealing with large scale networks.

A. Network Topology

We consider a ZigBee cluster-tree topology as shown in figure 1:

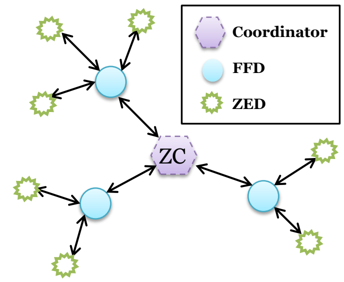

Fig. 1. Zigbee Cluster-tree topology

IEEE 802.15.4/ZigBee defines two types of devices: full function devices and reduced function devices:

- Full Function Devices (FFD): implement the full IEEE 802.15.4/ZigBee protocol stack.
- Reduced Function Devices (RFD): implement a subset of the protocol stack.

Regarding the devices role in the network, ZigBee identifies three device types:

- A ZigBee end-device corresponds to an IEEE RFD or FFD acting as a simple device.
- A ZigBee router is an FFD with routing capabilities.
- The ZigBee coordinator (one in the network) is an FFD managing the whole network.

B. ZigBee Network Formation and Address As-signment

The association procedure occurs in the presence of a coordinator as defined in the ZigBee standard [2]. The node asks for association and gets a network short address in reply.

The ZigBee coordinator determines the maximum number of children (Cm) any device is allowed to associate within its network. From these children, a maximum number of routers (Rm) can be router-capable devices. The remaining devices shall be reserved for end devices. Every device has an associated depth which indicates the minimum number of hops a transmitted frame must travel, using only parent-to-child links, to reach the ZigBee coordinator. The ZigBee coordinator itself has a depth of 0, while its children have a depth of 1. Multi-hop networks have a maximum depth that is greater than 1. The ZigBee coordinator also determines the maximum depth of the network (Lm).

Given the values of Cm, Rm, and Lm, we may compute the function, Cskip(d), essentially the size of the address sub-block being distributed by each parent at that depth to its router-capable child devices for a given network depth, d, as follows:

$$Cskip(d) = \begin{cases} 1 + Cm(Lm - d - 1) & Rm = 1 \\ \frac{1+Cm-Rm-CmRm^{Lm-d-1}}{1-Rm} & \text{otherwise} \end{cases} \quad (1)$$

If a device has a Cskip(d) value of 0, then it shall not be capable of accepting children and shall be treated as a ZigBee end device.

A parent device that has a Cskip(d) value greater than 0 shall accept child devices and shall assign addresses to them differently depending on whether or not the child device is router-capable. Network addresses shall be assigned to router-capable child devices using the value of Cskip(d) as an offset. A parent assigns an address that is 1 greater than its own to its first router-capable child device. Subsequently assigned addresses to router-capable child devices are separated from each other by Cskip(d). A maximum of nwkMaxRouters of such addresses shall be assigned. Network addresses shall be assigned to end devices in a sequential manner with the n$^{(th)}$ address, A_n, given by the following equation:

$$A_n = A_{parent} + Rm * Cskip(d) + n \quad (2)$$

Where 1 < n <(Cm-Rm) and A_{parent} represents the address of the parent.

The Cskip(d) values for an example network having Cm=4, Rm=4 and Lm=3 are calculated and listed in table I.

TABLE I
EXAMPLE OF ADDRESSING OFFSET VALUES FOR EACH GIVEN DEPTH WITHIN THE NETWORK

Depth in the Network,d	Offset Value, Cskip(d)
0	21
1	5
2	1
3	0

Figure 2 illustrates the network address assignment with the calculated addresses of each node.

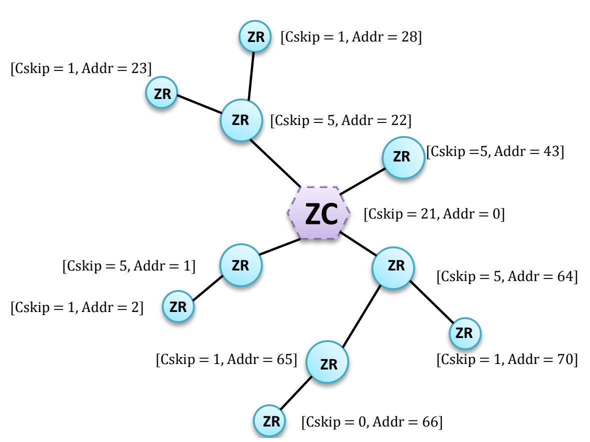

Fig. 2. Example of address assignment in a ZigBee Network

C. ZigBee Cluster-Tree Routing Protocol

The ZigBee cluster-tree routing protocol is a hierarchical routing protocol [2]. If the destination is a descendant of the device, this latter shall route the packet to the appropriate child. If the destination is not a descendent, the device shall route the frame to its parent. For a ZigBee router with address A at depth d, if the following logical expression is true, then a destination device with address D is a descendant:

A <D<A+Cskip(d- 1)

If it is determined that the destination is a descendant of the receiving device, the address N of the next hop device is given by:

N=D, for ZigBee end devices, where D>A+Rm*Cskip(d), and otherwise:

$$N = A + 1 + \left\lfloor \frac{D - (A+1)}{Cskip(d)} \right\rfloor * Cskip(d) \quad (3)$$

If the destination address is not a descendant, the device relays the packet to its parent.

Let's consider the network scenario illustrated in Figure 2 and the following network parameters: Lm = 3; Cm = 4; Rm = 4. The Cskip values are presented in table I

If ZR 0x0002 transmits a message to ZR 0x0041, the tree-routing protocol behaves as follows: 1. ZR 0x0002 builds the data frame and sends it to its parent (0x0001). The most relevant fields of this data frame are outlined next :

- MAC destination address: 0x0001;
- MAC source address: 0x0002;
- Network Layer Routing Destination Address: 0x0041;
- Network Layer Routing Source Address: 0x0002;

2. ZR 0x0001 receives the data frame, realizes that the message in not for him and has to be relayed. The device checks its neighbour table for the routing destination address, trying to find if the destination is one of its child devices. Then, the device checks if the routing destination address is a descendant that results in:
0x0001 <0x0041 < 0x0001 + 21
Note that ZR 0x0001 is in depth 1 in the network. After verifying that the destination is not a descendant, ZR 0x0001 routes the data frame to its parent, ZC 0x0000. The most relevant fields of this data frame are outlined next:

- MAC destination address: 0x0000;
- MAC source address: 0x0001;
- Network Layer Routing Destination Address: 0x0041;
- Network Layer Routing Source Address: 0x0002;

3. ZC 0x0000 receives the data frame and verifies if the routing destination address exists in its neighbor table. After realizing that the destination device is not its neighbor, since the ZC is the root of the tree and cannot route up, the next hop address is calculated as follows:

$$N = 0x0000 + 1 + \left\lfloor \frac{0x0041 - (0x0000 + 1)}{21} \right\rfloor * 21 \quad (4)$$

The next hop address results in N = 64 (decimal) = 0x0040. The most relevant fields of this data frame are outlined next:

- MAC destination address: 0x0040;
- MAC source addres: 0x0000;
- Network Layer Routing Destination Address: 0x0041;
- Network Layer Routing Source Address: 0x0002;

4. ZR 0x0040 receives the data frame and checks its neighbor table for the routing destination address. After verifying that the address is its neighbour, the message is routed to it. The next hop is assigned with the short address present in the respective neighbor table entry. The most relevant fields of this data frame are outlined next:

- MAC destination address: 0x0041;
- MAC source address: 0x0040;
- Network Layer Routing Destination Address:0x0041;
- Network Layer Routing Source Address: 0x0002;

D. Z-Cast: Zigbee Multicast Routing mechanism

In this section, we present an overview of the Z-Cast Multicast routing mechanism. Z-Cast represents a solution to support multicast in ZigBee-based WSNs as defined in [1]. It is designed to ZigBee cluster-tree WSN with different groups based on the type of sensory information as defined in [3]. Z-Cast mechanism rely on a Multicast routing table in the Zigbee Coordinator and in each ZigBee router to store and know about membership information of all groups. In what follows, we present the details of this protocol.

1) Multicast Routing Table: The specification of the Z-Cast mechanism defines a Multicast Routing Table MRT that must be created inside each ZigBee Router. The role of this table is similar to the routing table in traditional networks in storing the membership table status of the children. The structure of the MRT is illustrated in the table II:

TABLE II
MULTICAST ROUTING TABLE (MRT)

Multicast_group_address	GMS_address
multicast_Addr1	node_address1, node_address2
multicast_Addr2	node_address2, node_address2
multicast_Addr3	0

The Multicast Routing Table has two fields :

- Multicast_group_address : 16 bits short address that identifies a certain group.
- GMS_address: contains the list of the network short addresses of nodes being members of the group along the cluster tree network.

2) Routing Table Update: The MRT table entries must be updated for every join and leave operations in the network. When a node joins a certain group, all ZigBee Routers between the joining node and the ZigBee Coordinator must add the multicast address of the group to the *Multicast_group_address* field and the address of the joining node to the *GMs_address* field of their *MRT* tables because the multicast message will be forwarded to the ZigBee Coordinator before reaching the group members. Thus, a ZigBee Router must know not only the membership information of its directly associated nodes, but also all the membership information of the child routers of its tree.

By reaching a ZigBee router, updating the MRT is very important as the proposed mechanism relies on this table to decide if the multicast data will be forwarded by unicast or multicast, or instead it will be discarded. When a node leaves a multicast group, all ZigBee Routers that are between the leaving node and the ZigBee Coordinator must delete the node address from the GMs_address. In the case when all the members have left the group, the corresponding multicast group address entry must also be deleted from the *MRT* table.

3) Routing in ZigBee Coordinator: A ZigBee Router can only check its child routers by checking its *MRT* table, and it cannot check the other ZigBee Routers in the network. The authors have proposed to send the multicast message to the ZigBee Coordinator before sending it to the group members because the ZigBee Coordinator is the only node in the network that can send messages to any device in the network. They propose to add a flag to the multicast message to indicate that the multicast message has already been treated by the ZigBee Coordinator.

When a frame is received by the ZigBee Coordinator, it analyzes the frame and checks if the destination address is a multicast or a unicast address. If it is a multicast address, the ZC will add a flag to the frame and sends it to all its directly connected child Routers. The flag is necessary to indicate that the frame is treated by the ZigBee Coordinator. If a multicast frame comes to the ZigBee Router without the flag, the packet must be sent to the parent device until reaching the ZigBee Coordinator. If the destination address of the frame contains a unicast address, the default cluster-tree routing will be applied.

Algorithm 1 The ZC Multicast routing algorithm

while Receive a packet **do**
  if destination address is a multicast address **then**
    $flag \leftarrow 1$
    Route to the direct ZRs according to MRT table
  else
    Apply the cluster tree routing
  end if
end while

When a group member wants to send a multicast packet to the other members belonging to its group, the request will be sent by unicast to the ZigBee Coordinator passing through all the routers. Then, the multicast packet is sent to the ZC and then to all the multicast group members according to the entries of the multicast routing table and the cluster-tree routing mechanism. The multicast algorithm implemented in the *ZC* is presented in Algorithm 1.

4) Routing in ZigBee Routers: When a multicast packet reaches a ZigBee Router, there are different possibilities:

- If the *multicast_group_ address* is not found in the (*MRT*), then the multicast packet will be discarded.
- If the *multicast_group_address* is found in the *MRT*, two different cases may occur :

– If the *GMs_address* field contains only one member address of the corresponding group, the packet will be transmitted by unicast to the group member by applying the default ZigBee cluster-tree routing algorithm. The unicast here is necessary because there is only one member in the leaf.
– If the *GMs_address* field contains two or more than two addresses of the corresponding group members, the packet will be transmitted to all its direct child nodes (ZigBee Routers and ZigBee End-Devices).

For the *ZigBee routers* that receive a multicast frame, the algorithm to be implemented is presented in Algorithm 2.

Algorithm 2 The ZR multicast routing algorithm

```
while destination address == a multicast address do
    if flag = 0 then
        forward the packet to the parent device
    else                                                    ▷ flag=1
        if multicast_group_address not found in MRT then
            Discard the packet
        else
            if multicast group address found in MRT  then
                if card(GMs_address) == 1 then
                    Apply the cluster tree routing
                end if
                if card(GMs_address) >= 2 then
                    send to all the direct child nodes
                end if
            end if
        end if
    end if
end while
```

In what follows, we present a limit in the Multicast Routing Table as defined in [1], and then we present an amelioration of this mechanism in the construction and the update of the Multicast Routing Table.

5) Problem in the MRT of Z-Cast: In [1] the Multicast Routing table update is performed when a node joins or leaves a group. So, every ZigBee router between the joined node and the Coordinator of the network must update the Multicast Table entry of the group. In the figure 3 we show an example of updating the multicast Table as defined in [1].

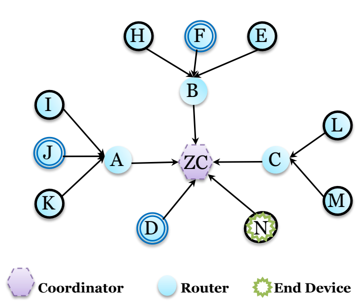

Fig. 3. A cluster Tree network with groups

In this example, we have considered a network where Cm=4, Rm=4 and Lm=3. The devices E, H, L, M, N, I and K belong to the same group having for example as a multicast group address 0xF801. The devices F,J and D belong to the same group having for example as a Multicat group address 0xF802 . The multicast routing tables are as presented in tables III and IV:

TABLE III
FINAL MRT UPDATE OF ZC

Multicast_group_address	GMs_address
0xf801	Network Short address of E
	Network Short address of H
	Network Short address of L
	Network Short address of M
	Network Short address of N
	Network Short address of I
0xf802	Network Short address of F
	Network Short address of J
	Network Short address of D

TABLE IV
FINAL MRT UPDATE OF NODE B

Multicast group address	GMs address
0xf801	Network Short address of E
	Network Short address of H
0xf802	Network Short address of F

Tables III and IV show that if the network have an important number of nodes belonging to a certain group, the memory space requirements increases.

In addition, every node in the network that have joined a group must inform all the intermediate routers of this new status, thus the number of update messages increases significantly especially when dealing with long depths which can lead to network congestion. For this reason, we can assume that the proposed Multicast routing table did not scale to large network size and low memory requirements of sensor nodes that have limited memory resources. In the next section we give our solution for this problem.

E. Amelioration of the Multicast Routing Table

The amelioration that we have proposed concerns the MRT construction and the MRT update:

1) MRT Construction Amelioration: When a node joins a multicast group, its parent updates its Multicast routing table. The parent node verifies if the node that it added to his multicast routing table is the first one in this group. If it is the case, this parent node will inform his parent node that it has in his descendants members of a group. Thus, the parent nodes will only store the group address and not the group member address which can reduce the memory storage in sensor nodes.

2) MRT Update Amelioration: If the router have already members that belong to the same group, it will not inform the parent nodes of this information because it will be a redundancy. Thus, the number of messages is reduced. The proposed Multicast routing table update mechanism algorithm is shown in algorithm 3:

Algorithm 3 Multicast routing table update mechanism

```
while When receive a group_join _indication from my child do
    if Multicast_group_address found in Multicast routing then
        Add short address to the multicast routing table
    else
        if (device_Type != Coordinator ) then
            Add a new Multicast_group_address
            Add the short address to the GMS_address field
            Send a group_join_request to parent
        else
            Add a new multicast_group_address
            Add the short address to the GMS_address field
        end if
    end if
end while
```

3) Example of Updating the Multicast Routing Table : Figure 3 illustrates a cluster tree network with groups. Nodes surrounded by a single circle represent group1 with Multicast group address 0xF801 and nodes surrounded by a double circle are the members of group 2 with a multicast group address 0xF802. We suppose that the network topology is already created and the nodes join securely the groups.

The node B updates its Multicast routing table after being informed that node E is a member of group 1 and informs its parent about the group as shown in figure 4 **(A)** , table V and table VI:

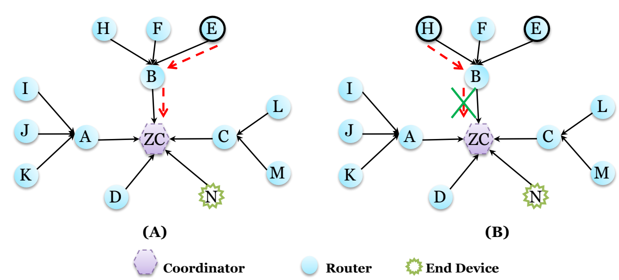

Fig. 4. Example of group_join_indication messages

TABLE V
MRT UPDATE OF NODE B AFTER A GROUP JOIN

Multicast group address	GMs address
0xf801	Network Short address of E

TABLE VI
ZC MRT UPDATE AFTER A GROUP JOIN INFORMATION BY NODE B

Multicast group address	GMs address
0xf801	Network Short address of B

Node B updates its Multicast routing table after being informed that node H is a member of group 1. Group 1 already exists in his multicast routing table. Thus, node B will not inform its parent about the group as shown in figure 4 **(B)**, table VII. In this case, ZC's MRT was not modified after adding a new member.

TABLE VII
MULTICAST ROUTING TABLE OF NODE B CONTAINING TWO MEMBERS

Multicast group address	GMs address
0xf801	Network Short address of E Network Short address of H

After updating all the Multicast routing tables of the network topology of figure 3; The multicast routing table of the ZigBee Coordinator is shown in table VIII.

TABLE VIII
MULTICAST ROUTING TABLE OF THE ZC WITH AMELIORATION

Multicast group address	GMs address
0xf801	Network Short address of B Network Short address of C Network Short address of A Network Short address of N
0xf802	Network Short address of A Network Short address of B Network Short address of D

The difference is very clear between the multicast routing tables III of the Z-Cast and VIII of the ameliorated Z-Cast. Thanks to our contribution, the MRT size is reduced considerably especially in the case of multiple group members of the same leaf in the cluster-tree topology.

This contribution scale to large network size as the number of update messages and the MRT size are reduced which responds to low memory and energy requirements of sensor nodes.

IV. PERFORMANCE EVALUATION OF Z-CAST MECHANISM

A. Experimental Settings and Development Tools

In this section, we describe the technologies used to carry out all the implementation and experimental work presented in this paper. Then we detail the performance evaluation that we have made on a real testbed.

The Open-ZB IEEE 802.15.4/ZigBee is supported by two hardware platforms: the MICAz and the TelosB motes. In our work, we used the TelosB platform. To monitor the network, we used Zmonitor (ZM) [13] which is a free tool for monitoring and controlling IEEE 802.15.4 Low Power Wireless Personal Area Networks (LOWPANs). We have integrated Z-Cast in open-ZB toolset [12] which is an open source implementation of the IEEE 802.15.4/ZigBee protocols, namely providing the following toolset :

- Implementation of beacon-enabled mode of the IEEE 802.15.4 protocol stack developed in nesC, under the TinyOS operating system for the CrossBow MICAz and TelosB motes;
- Implementation of the ZigBee Network Layer (including the IEEE 802.15.4)

B. Performance Evaluation

The performance metrics used for our evaluation are:Execution time of the Z-Cast mechanism, Memory Footprint, End to end delay, and Packet delivery ratio.

1) Execution time of Z-Cast mechanism : To compute the execution time of the Z-Cast mechanism, we have used the component *HilTimerMilliC* that provides a parameterized interface to a virtualized millisecond timer. *HilTimerMilliC* provides the interface *LocalTime* that we have used to get time before and after the execution of Z-Cast mechanism , then we have calculated the difference between the two obtained values .

TABLE IX
EXECUTION TIME OF Z-CAST FUNCTIONS

Z-cast mechanism functions	**Execution time (seconds)**
Routing(unicast/multicast)	1
Add a Multicast Group_address in the Multicast Routing Table	18
Update the Multicast Routing Table with a new Group member	14
Receive a Multicast group message	7

According to table IX, it is clear that the time of routing a unicast or multicast packet is negligible. The time to update the multicast routing table is a bit high but it does not influence the protocol performance because the multicast routing table update does not occur frequently.

2) Memory Footprint: A primary goal of Z-Cast is to provide a multicast routing algorithm which can realistically be deployed on hardware constrained sensor hardware. It is therefore important that Z-Cast can be implemented with realistically low overhead on RAM and ROM consumption. Table X examines Z-Cast impact on application footprint. We compare the ROM and RAM usage statistics for the implemented multicast protocol when compiled for the TelosB motes, with and without Z-Cast ; these statistics are generated by the TinyOS toolchain.

TABLE X
MEMORY FOOTPRINT

	ROM	RAM
Open_ZB	35054	3220
Open_ZB with Z_Cast	40552	3814

There is a 594-byte difference in RAM consumption between Z-Cast and the default Open-ZB implementation. The ROM overhead is larger by 5498 bytes, which is insignificant when compared to the ROM size of representative sensor hardware (e.g., 48 KB for TelosB). This result shows that the multicast routing protocol is added to the open-ZB implementation with little add-ons.

3) End-to-End Delay : Network delay is the total latency experienced by a packet to be routed in the network from source to destination. At the network layer, the end-to-end packet latency is the sum of processing delay, packet, transmission delay , queuing delay and propagation delay. The end-to-end delay of a path is the sum of the node delay at each node plus the link delay at each link of the path. A higher value of end to end delay means that the network is congested and hence the routing protocol doesn't perform well. Figure5 depicts the end to end delay when varying the number of hops.

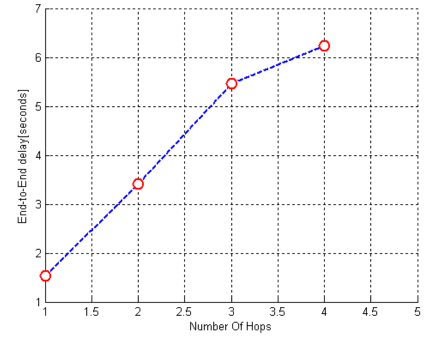

Fig. 5. Z-Cast End-to-end delay

According to this figure, the end-to-end delay for Z-Cast increases as the number of hops increases. This result is predictable as the multicast message requires an execution time which is the sum of the time executions at each path in the network.

4) Packet Delivery Ratio : The Packet Delivery Ratio (PDR) is the number of successfully delivered legitimate packets to number of generated legitimate packets.

$$PDR = \frac{Totalnumberofpacketssent}{Totalnumberofpacketsreceived} \quad (5)$$

A higher value of PDR indicates that most of the packets are being delivered to the higher layers and is a good indicator of the protocol performance.

To obtain the packet delivery ratio, we have made an experiment which consists as follows: We have sent 10 multicast packets over the radio to destinations that have different hops from the source (from 1 to 4). The average packet delivery ratio for Z-Cast is shown in figure 6.

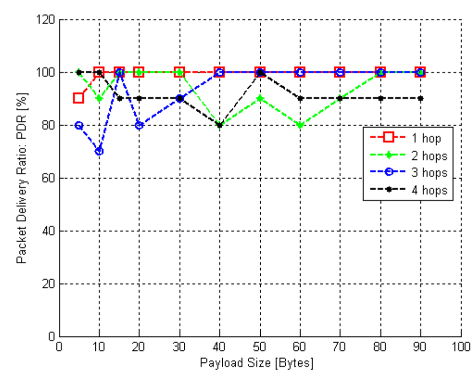

Fig. 6. Z-Cast packet delivery ratio

According to this figure, our implementation is efficient as the PDR is always more than 90 % even if the distance between the destination and the source is 4 hops.

V. CONCLUSION

In this paper, we addressed the muticast routing in wireless sensor networks. This issue is very critical as this type of routing improves efficiency and reduces path length; which is very important especially when dealing with low memory and energy constraints.

Z-cast is a multicast routing mechanism designed to ZigBee cluster-tree WSNs. However, it was not implemented in a real WSN platform. We have studied this protocol and we have noticed that this protocol requires higher memory and communication overhead mainly when dealing with large scale networks. Then, we proposed an amelioration of this mechanism and integrated it in Open-ZB which is an open source IEEE/802.15.4 ZigBee implementation over TinyOS.

We have analyzed the effectiveness of our proposal by making several experiences to measure the end to end delay, the time execution and the packet loss. We have then demonstrated that the mechanism is lightweight and minimizes the communication overhead in the ZigBee network.

Future works includes; the optimization of group routing performance with respect to overheads and limited resources, and the design of a complete group communication protocol that offers secutity in multicast routing in ZigBee cluster-tree networks.

References

[1] Olfa Gaddour , Anis Koubaa, Omar Cheikhrouhou, Mohamed Abid. Z-Cast: A Multicast Routing Mechanism in ZigBee Cluster-Tree Wireless Sensor Networks, in the Third International Workshop on Sensor Networks (SN 2010), in conjunction with ICDCS 2010, Genoa, Italy, June 21-25, 2010.

[2] Zigbee 2006 specification,"ZigBee document 064112, http://www.zigbee.org/", 2006.

[3] O. Gaddour, A. koubaa, and M. Abid, "SeGCom: A secure group communication in cluster-tree wireless sensor networks," IEEE First International Conference on Conference on Communications, and Networking, COMNET,pp. 1-7, November 2009.

[4] Anis Koubâa and Mario Alves and Edoardo Tovar, IEEE 802.15.4: a Federating Communication Protocol for Time-Sensitive Wireless Sensor Networks, Book Sensor Networks and Configurations: Fundamentals, Techniques, Platforms, and Experiments, Ed. (N. P. Mahalik)", Springer-Verlag, Germany, 2006

[5] A. Sheth, B. Shucker, R. Han, VLM2: A Very Lightweight Mobile Multicast System forWireless Sensor Networks, In Proceedings of IEEEWireless Communications and Networking Conference (WCNC), 2003.

[6] B. Chen, K. Muniswamy-Reddy, M. Welsh. Ad-Hoc Multicast Routing on Resource-Limited Sensor Nodes, In Proceedings of the Second ACM/Sigmobile workshop on Multi-hop Ad Hoc Networks: from theory to reality (REALMAN'06), 2006.

[7] S. Wu, K.S. Candan, GMP: Distributed geographic multicast routing in wireless sensor networks, In Proceedings of ICDCS, 2006

[8] A. Juan Sanchez, M. Pedro Ruiz, Ivan Stojmenovic. GMR: Geographic Multicast Routing forWireless Sensor Networks. In Proceedings of the third Sensor and Ad Hoc Communications and Networks (SECON '06), 2006.

[9] J. G. Jetcheva and D. B. Johnson. Adaptive Demand-Driven Multicast Routing in Multi-Hop Wireless Ad Hoc Networks. In 2001 ACM International Symposium on Mobile Ad Hoc Networking and Computing (MobiHoc2001), pages 33-44, October 2001.

[10] Reinisch, C; Kastner, W; Neugschwandtner, G; Emerging Technologies and Factory Automation, 2007. ETFA. IEEE Conference , 2007 , Page(s): 1380 - 1383

[11] S. K. Das, B. S. Manoj, and C. S. R. Murthy. A Dynamic Core Based Multicast Routing Protocol for Ad hocWireless Networks. In Proc. of 3rd ACM international symposium on Mobile ad hoc networking and computing, pages 24-35, New York, NY, USA, 2002. ACM Press.

[12] Open-ZB open-source toolset for the IEEE 802.15.4/ZigBee protocols website. http://www.open-zb.net.

[13] http://www.z-monitor.org/

[14] Singh, Y. Chaba, Y. Jain, M. Rani, P.GJ Univ of Sc and Tech, Hisar, India :" Performance Evaluation of On-demand Multicasting Routing Protocols in Mobile Adhoc Networks", in Recent Trends in Information, Telecommunication and Computing (ITC), 2010 International Conference on Date:12-13 March 2010.

[15] JC.W. Wu and Y.C. Tay,"AMRIS: A Multicast Protocol for Ad Hoc Wireless Networks","IEEE Military Communications Conference (MILCOM-99), Atlantic City, NJ", November,1999, p-p: 25-29

[16] Elizabeth M. Royer and Charles E. Perkins, Multicast Ad hoc On Demand Distance Vector (MAODV) Routing, Proceedings of ACM MobiHoc01, Long Beach, CA,2000,p-p:33-44

[17] Jorjeta G. Jetcheva and David B. Johnson, Adaptive Demand-Driven Multicast Routing in Multi-Hop Wireless Ad Hoc Networks, Proceedings of ACM MobiHoc01, Long Beach, CA",October 2001

[18] M. Mauve, and H.Fuler, and J. Widmer, and T. Lang, Position-Based Multicast Routing for Mobile Ad-Hoc Networks, TR-03-004, Department of Computer Science, University of Mannheim, March 2003

[19] Simek, M. and Kosmony, D. and Silva, J. S. , Multicast Routing in Wireless Sensor Network, in 31st International Conference, Telecommunication and Signal Processing, November 2008.

[20] A. Sheth, B. Shucker, R. Han, VLM2: A Very Lightweight Mobile Multicast System for Wireless Sensor Networks, In Proceedings of IEEE Wireless Communications and Networking Conference (WCNC), 2003.

[21] S. Wu, K.S. Candan, GMP: Distributed geographic multicast routing in wireless sensor networks, In Proceedings of ICDCS, 2006.