Z-Cast: A Multicast Routing Mechanism in ZigBee Cluster-Tree Wireless Sensor Networks

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***Abstract*—Group communication in Wireless Sensor Networks (*WSNs*) requires an efficient multicast routing mechanism due to inherent resources and computing constraints of sensor nodes. ZigBee, which is a standard protocol that represents a very prominent technology for WSNs, does not consider multicast routing in its specification. In this paper, a *group* is defined as a set of nodes that share the same sensory information. The main contributions of this paper are two-folded: First, we propose Z-Cast, an efficient multicast routing mechanism for groups that share the same sensory information in a cluster-tree WSNs. Second, we show how to integrate the Z-Cast mechanism in open-ZB which is an open source IEEE 802.15.4/ZigBee implementation. Finally, we demonstrate the efficiency and backward compatibility of our proposal with the standard specification.**

I. Introduction

Multicast routing is a challenging problem in wireless sensor networks (WSNs), mainly for supporting group communication. There have been a lot of proposals in this context for ad hoc networks such as [1], [2], [3],[4],[5], which are based on different design principles. However, they are not suitable for direct application in WSNs as they are designed to deal with nodes with higher computation and storage capacities.

The IEEE 802.15.4/ZigBee [6] standard protocols have been shown as prominent technologies for WSNs [7]. However, this standard protocol stack presents some gaps and limitations that were addressed and amended in the literature [8], [9], [10]. In this paper, we address the problem of Multicast in ZigBee cluster-tree networks, as it has not been defined in the standard specification. In fact, the ZigBee Network Layer does not define any Multicast mechanism neither in terms of routing nor in terms of addressing. This lack of Multicast support represents a gap in the standard as far as group communication is considered.

Group communication is an important topic in WSNs and has attracted several research works [11], [12]. However, the grouping semantic may be different depending on the assumptions and objectives of the study. For instance, in [13], the authors have defined a *group* as a set of sensor nodes that share the same sensory information. The main objective of [13] was to define a secure communication mechanism for a group of nodes sharing the same information in a WSN, but they did not propose any Multicast routing mechanism for data transfer among group members. The use of Multicast routing is of a great benefit for this type of applications, as it will facilitate the delivery of private data exclusively to group members. However, providing efficient Multicast routing in WSNs poses particular challenges as compared to unicast data delivery, especially since the overhead needs to be kept very low due to the limited energy resources of sensor nodes. Using Multicast protocols, the bandwidth requirement and energy consumption significantly reduce, as the number of transmission decreases, which is in-line with WSNs requirements.

In the literature, there are several research studies that have proposed mechanisms to support Multicast particularly for WSNs [14], [15], [16], [17], [18]. Each of these works relies on a specific and different grouping concept. However, to the best of our knowledge, there has been no previous work that addressed the support of Multicast in ZigBee-based WSNs, which is the main objective and the core contribution of this paper.

ZigBee defines three types of network topologies, namely *star*, *tree*, and *mesh* networks. All these topologies have a main device that is responsible of initializing, maintaining, and controlling the network, which is refereed to the *ZigBee coordinator*. The star topology has a *ZigBee Coordinator* through which all other devices join the network, synchronize themselves and communicate together. For the tree and mesh networks, devices can communicate with each other in a multi-hop fashion. These networks are created and maintained by one ZigBee Coordinator and may contain several ZigBee Routers, which provide synchronization services to their neighbor nodes (children), and route their data. A device can join a network as an End-Device (ZED) by associating with the ZigBee Coordinator or a ZigBee Router. In ZigBee, a device is considered to have successfully joined a network if it can obtain a 16-bit network address from the ZigBee Coordinator or a Router. The standard also specifies a distributed address assignment scheme, which allows a parent device to locally compute addresses for child devices.

In this paper, we are particularly interested in the ZigBee cluster-tree topology because it has many advantages when compared to the other topologies. The cluster-tree topology is especially designed to provide a good balance between low-power consumption, as it supports power saving through adaptive duty cycling, and real-time requirement, as it provides guaranteed time slots (GTS) for critical traffic [19].

The remainder of this paper is organized as follows: In Section II, we discuss related works on Multicast routing in ad hoc and WSNs. In Section III, we present the network model. In Section IV, we describe our proposed Multicast routing mechanism. Then, we give an analytical analysis and the performance evaluation in Section V. Finally we conclude and provide future works in Section VI.

II. Related work

Multicast is the transmission of packets to a group of hosts identified by a single destination address and hence is intended for group-oriented computing. This transmission pattern efficiently utilizes the bandwidth and energy. $WSNs'$ Multicast communication is usually used between base stations and sensor nodes, for example, reinstalling sensor's sampling rate or base station querying information. Multicast communications are rarely used between peer-to-peer sensor nodes [20].

Some Multicast routing protocols for ad-hoc networks have been proposed [2], [3], [4], [5]. Multicast routing for Ad-hoc networks can be classified into mesh based and tree based protocol according to the topology.

Mesh-based Multicast routing protocols such as [21] and [22] expanded a Multicast tree with additional paths that can be used to forward Multicast data packets when some of the links fail. However, the maintenance of these structures through periodic broadcasts and the large amount of nodes which are required to forward Multicast data messages make them impractical for sensor networks. Tree-based Multicast routing protocols such as in [23], [18], [24] require less relay nodes. Multicast tree should be rebuilt when links between nodes become invalid. In addition, periodic flood messages will increase the control overhead, which is unsuitable for WSNs.

Since these works have been proposed for ad hoc networks, they cannot be directly applied in WSNs because they are designed to deal with nodes with big storage capacity and high computation power. There have been therefore a lot of Multicast routing mechanisms proposed for WSNs.

In[14], the authors defined a mobile Multicast system for wireless sensor networks. This system builds Multicast support characterized by hierarchy and mobility. The addressing scheme corresponds to 8 bit *ID* for nodes and groups. This mechanism uses unicast to do the node-to-base station routing and Multicast to perform 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 the router state and the code size. However, the implementation is so specific such that the mechanism 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 [15], the authors proposed an ad-hoc Multicast routing for sensor nodes. They used the common broadcast flooding process for the Multicast route discovery. In this proposal, the sender broadcasts a route discovery message to determinate the shortest path to the members of the Multicast group. The intermediate nodes compare the hops number of the discovery message with the own maintained number of hops to source. If the message hops count is less than the nodes own hops, the node updates the routing information. In this downstream direction, intermediate nodes only rebroadcast the discovery message to neighbors. However, the path selection with the minimal number of hops may not be the best solution, since it may exist longer links but with the much better characteristics of transmission quality.

In [16], the authors proposed a grid Multicast routing Protocol. It consists in routing data between the source and destination via the energy shortest distance. They assumed that the longer hop between the pair of nodes consumes more energy than the smallest one. Therefore, they used the rectilinear hop-by-hop communication in the sensor network formed as grid shape. However, in terms of the number of nodes involved in the Multicast tree transmission, this Multicast protocol induces a big bandwidth consumption. This is due to the fact that the protocol aims to use a large number of nodes (as the energy efficient solution) which consume the larger bandwidth resources.

In [17], another geographic Multicast routing for WSNs was proposed. This mechanism is based on using only the position information for the Multicast routing in the network, which avoids the undesirable broadcast flooding. However, the performed simulations in this work only consider a small number of Multicast receivers, which raise the question about what results upon the real implementation to the motes with constrained memory space and also how to deal with a bigger numbers of Multicast receivers.

In this paper, we particularly tackle the problem of Multicast in ZigBee-based networks. The standard specification did not define any Multicast data routing mechanism, which represents a limitation to efficiently support group communications in ZigBee-based WSNs. In this paper, we propose a solution to this limitation. The main contributions of this paper are two-folded:

- First, we propose Z-Cast, a Multicast routing mechanism for ZigBee-based cluster-tree WSNs.
- Second, we show that Z-Cast can be easily integrated and implemented into the IEEE 802.15.4/ZigBee standard protocol stack, thus maintaining backward compatibility with these protocol standards, i.e. devices that do implement Z-Cast remain fully interoperable with those that do not.

III. System Model and Background

A. Network Model: ZigBee Cluster-Tree Network

We consider a ZigBee cluster-tree network as shown in Fig. 1. The ZigBee cluster-tree topology contains a special

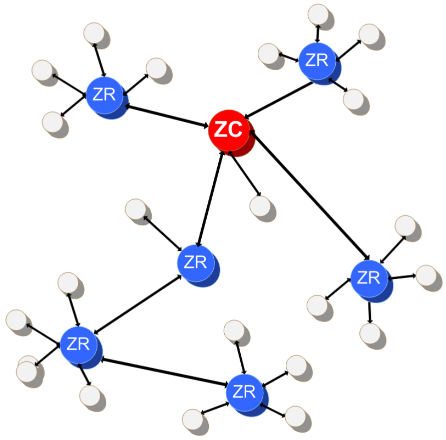

Fig. 1. The Network Model

node called ZigBee Coordinator (*ZC*), which identifies the entire network. In addition, in a tree network, some special devices may have the ability to allow the association from other nodes. These nodes are called ZigBee Routers (*ZR*), which defines a cluster. Other end-devices with no ability to associate other devices are called ZigBee End-Devices (*ZED*). In the cluster-tree topology, tree routing is used which induces a single path between any pair of nodes. In what follows, we describe the functionalities of each node type of the aforementioned cluster-tree network model as described in the ZigBee standard:

- *The ZigBee Coordinaor*: also referred to as *Base Station*, is the root that identifies the whole network. It is responsible of performing critical functions such as assigning device addresses, controlling the network formation and operation, and collecting all the data. There is only one *ZC* in each network. The base station manages its cluster and all the other clusters in the network.
- *The Zigbee Router*: has the ability to execute routing algorithms and forward messages to and from the other devices. It is able to establish and maintain multiple connections either as a parent or a child. Each Router receives the information flows coming from its child nodes of its local cluster, or from other ZigBee routers, and then forwards the traffic to the *ZC* or other ZigBee Routers.
- *The ZigBee End-Device*: it has limited resources. It is optimized for very low power operation. It does not allow association and does not participate in routing. Each ZigBee End-Device is associated to the cluster-tree network through only one ZigBee Router.

B. ZigBee Address Assignment

In ZigBee, network addresses are assigned to devices by a distributed address assignment scheme [6]. This mechanism provides to each potential parent (*ZC* and *ZRs*) a finite sub-block of unique network addresses based on the maximum number of children, depth and the number of routers in the network. Before creating a network, the ZigBee Coordinator presets the configuration values of the maximum number of child nodes of a ZigBee Router (*Cm*), the maximum number of child routers of a ZigBee Router (*Rm*), and the depth of the network (*Lm*). Note that a child of a router can be a router or an end-device, so (*Cm* >=*Rm*). The coordinator and routers can have at most *Rm* child routers and at least (*Cm* - *Rm*) child end-devices. The addresses of the ZigBee end-devices are assigned in a top-down fashion. At the ZigBee Coordinator level, the whole address space is logically partitioned into (*Rm* + 1) blocks. The first *Rm* blocks are assigned to the ZigBee Coordinator′s child routers and the last block is reserved for the *ZC* child end-devices. From *Cm*, *Rm*, and *Lm*, each router computes a parameter called *Cskip* to derive the addresses of its children. The *Cskip* of the ZigBee Coordinator or a ZigBee Router in depth *d* is defined in Eq. 1, as:

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

A parent device that has a *Cskip*(*d*) value of zero means that it is not capable of accepting children and must be treated as an end-device. A parent device that has a *Cskip*(*d*) value greater than zero can accept devices and assign them addresses, if its remaining address space allows. The *ZigBee Coordinator* has a *depth d=0*, and *d* increases by one after each level. The address assignment mechanism begins from the ZigBee Coordinator by assigning the address 0 to itself.

For a certain parent node located at depth *d* and has the address A_{parent}, the corresponding number of child ZigBee end-devices *N* is between 1 and *Cm-Rm*. The A_{child} address of the N^{th} child *router* having its parent node at depth *d* is determined according to Eq. 2.

$$A_{childrouter,n} = \begin{cases} A_{parent} + (n-1) * Cskip(d) + 1, & n = 1 \\ A_{parent} + (n-1) * Cskip(d), & \text{n} > 1 \end{cases} \quad (2)$$

Where *n* is the number of child routers.

For *end-devices*, the network addresses must be sequentially assigned. The address of the N^{th} child ZED , $A_{enddevice,n}$ is given by Eq. 3:

$$A_{enddevice,n} = A_{parent} + (d) * Cskip(d) + n \quad (3)$$

Where *n* is the number of child end devices.

In what follows, we illustrate the concept of address assignment through the following example shown in Fig. 2. In this example, we set the cluster-tree network parameters *Cm* = 5, *Rm* = 4, and *Lm* = 2. The *Cskip* is equal to 1 + 5 + - 4 * 4^{2-0-1} = 6 by applying Eq. 1.

Then, the child routers directly associated to the ZigBee Coordinator will be assigned the addresses 0 + (1 - 1) * 6 + 1 = 1, 0 + (2 - 1) * 6 + 1 = 7, 0 + (3 - 1) * 6 + 1 = 13 by applying Eq. 2. The address of the only child end device of the coordinator is 0 + 4 * 6 + 1 = 25 by applying Eq. 3.

C. ZigBee Tree Routing Protocol

In this section, we present a brief overview of the tree routing protocol for ZigBee cluster-tree networks. The tree

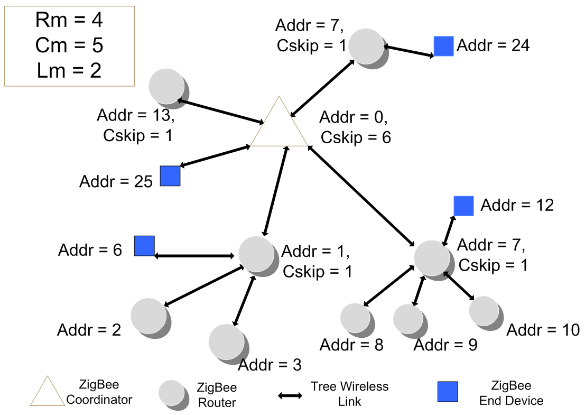

Fig. 2. An example of the ZigBee address assignment mechanism

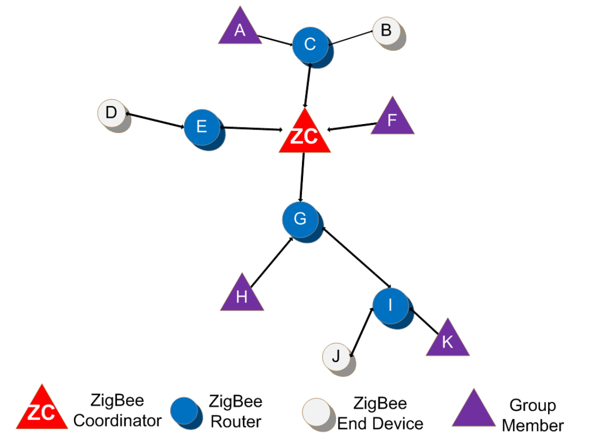

Fig. 3. An example of a Multicast group in the ZigBee cluster-tree network

routing protocol is simple and operates as follows: when a ZigBee router receives a packet, it first checks if it is the destination or if one of its child end-devices is the destination. In this case, this device accepts the packet or forwards it to the corresponding child node. Otherwise, it forwards the packet to its parent. Formally, for a ZigBee router in depth d and with address A_{parent}, it sends the packets to its descendants if the destination address satisfies:

$$A_{parent} < A_{dest} < A_{parent} + Cskip(d-1) \quad (4)$$

In this case; the address of the next hop child device in the downstream direction is determined as shown in Eq. 5:

$$A_{next-hop} = A_{parent} + 1 + \left[\frac{A_{dest} - (A_{parent} + 1)}{Cskip(d)} \right] * Cskip(d) \quad (5)$$

Where $A_{next-hop}$ designates the address of the next hop, A_{parent} is the address of the parent node and A_{dest} is the final destination address. If the destination is not a descendant of this device, this packet will be forwarded to its parent.

IV. Z-Cast: ZigBee Multicast Routing

In this section, we present the Z-Cast mechanism, which represents a solution to support Multicast in ZigBee-based WSNs. The objective of Z-Cast is to provide an efficient data routing among all group members. We consider a ZigBee cluster-tree *WSN* with different groups, where members of each group share the same sensory information as defined in [13]. For instance, Fig. 3 illustrates the grouping concepts and shows a group of four nodes *A*, *F*, *H* and *K*.

It is clear that simple communication between group members through simple broadcast is not effective and may degrade the performance of the WSN. The use of Multicast routing is thus more efficient to improve throughput and reduce energy consumption. It is therefore necessary that a message sent from a group member only reaches the tree leafs that contain the group members. To achieve this objective, we propose to create a *Multicast Routing Table* (*MRT*) in the ZigBee Coordinator and in each ZigBee Router, to store membership information of all the groups. The proposed mechanism takes into consideration the number of the child routers being members of a certain group to decide about the way that the packet will be forwarded through the rest of the tree. In what follows, we first present the main features of the Multicast routing table, then we present the Multicast routing algorithm for ZigBee cluster-tree WSNs.

A. The Multicast Routing Table

The Z-Cast Multicast mechanism relies on the creation of Multicast routing tables inside each ZigBee Router, to store the membership information of all nodes belonging to a certain group in the network.

The Multicast routing table contains two fields : *Multicast_group_address* and *GMs_address*.

The *Multicast_group_address* field is a 16 bit address; it contains the group Multicast address that identifies a certain group. The *GMs_address* field contains the list of the addresses of the child nodes being members of the group all along the cluster-tree network. Table I illustrates an example of the Multicast routing table in a ZigBee Router.

TABLE I
THE MULTICAST ROUTING TABLE

Multicast_group_address	GMs_address
multicast_Addr1	node_address1, node_address2
multicast_Addr2	node_address2, node_address3,
multicast_Addr3	0

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 -if it does not exist -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 broadcast, 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 (*ZC*) 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. Fig. 4 illustrates an example of a joining operation where the ZigBee Routers *G* and *I* update their Multicast routing table accordingly, after nodes *H* and *K* join the existing group. In this example, we have considered a network where *Cm* = 4, *Rm* = 4, and *Lm* = 3.

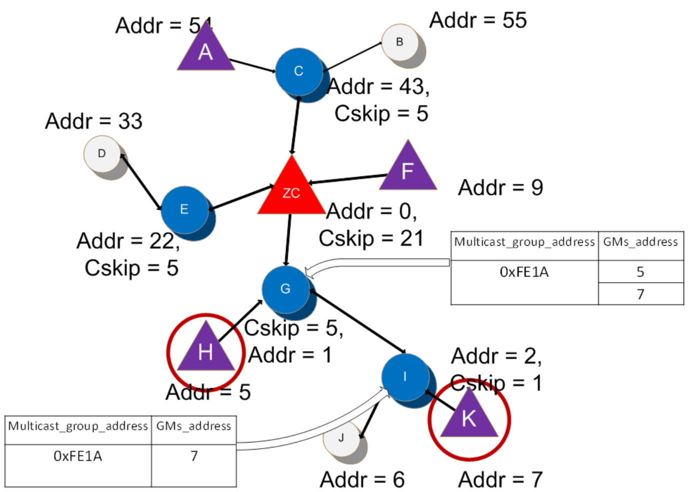

Fig. 4. An example of updating the Multicast table

B. The Z-Cast Tree Routing Mechanism

In this section, we present the Z-Cast routing mechanism for ZigBee cluster-tree WSNs. The Z-Cast routing mechanism comprises two main operations depending where it is implemented: (1) An algorithm to be implemented in the *ZC* to decide on how to route packets and (2) an algorithm to be implemented in each ZigBee Router to route Multicast data efficiently in the network.

1) 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. It is then necessary 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 and thus, we will be sure that the message will reach all the leafs and will be treated by all the ZigBee Routers. We propose then to add a flag to the Multicast message to indicate the 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 sent from 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. By adding this flag, Z-Cast guarantees that the frame will reach all ZigBee Routers in the network because the ZigBee Coordinator is the only node that has the ability to send frames to all nodes in the ZigBee wireless sensor network as ZigBee Routers are limited to their direct parents and children. If the destination address of the frame contains a unicast address, the default cluster-tree routing will be applied.

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.

Algorithm 1 The ZC Multicast routing algorithm

```
while Receive a packet do
    if destination address is a Multicast address then
        flag ← 1
        Route to the direct ZRs according to MRT table
    else
        Apply the cluster tree routing
    end if
end while
```

2) 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 field *GMs_address* 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 field *GMs_address* 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). Thus, the ZigBee router does not need to know the complete membership information of all its direct child nodes. This will considerably reduce the memory size of our Z-Cast mechanism.

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
```

C. An Illustrative Example

In what follows, we illustrate the Z-Cast routing algorithm through a concrete example. We consider the same group presented in Fig. 3 where node *A* wishes to send a Multicast packet to the other members belonging to its group. According to the algorithm, the request is firstly sent to the *ZC* by unicast (steps 1 and 2) as shown in Fig. 5.

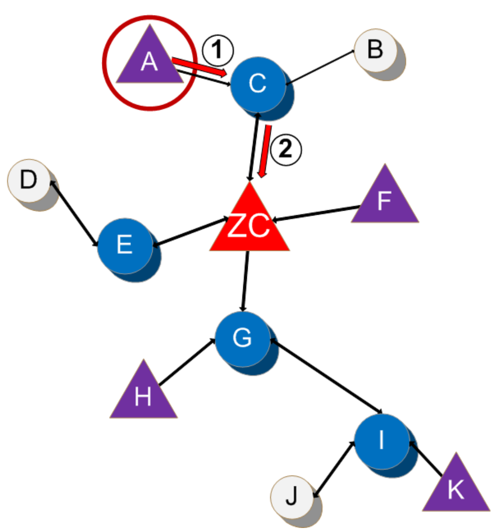

Fig. 5. A node sending the Multicast message by unicast to the BS

The *ZC* checks the address type and then checks the *MRT* table which contains more than two group members, it then broadcasts the packet to its direct child nodes (step 3) as shown in Fig. 6.

The ZigBee Router *C* has only one group member *A* in its child nodes, it does not resend the packet to *A* because it is the source node.

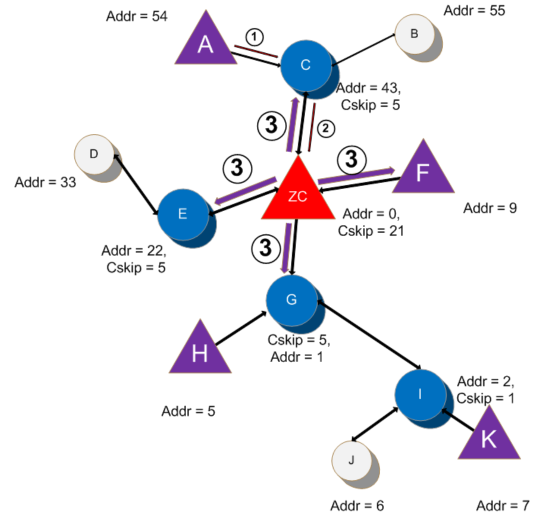

Fig. 6. The ZC broadcasting the Multicast message to its direct routers

The ZigBee Router *E* has no members in its cluster belonging to this Multicast group, the packet then is discarded, as shown in Fig. 7.

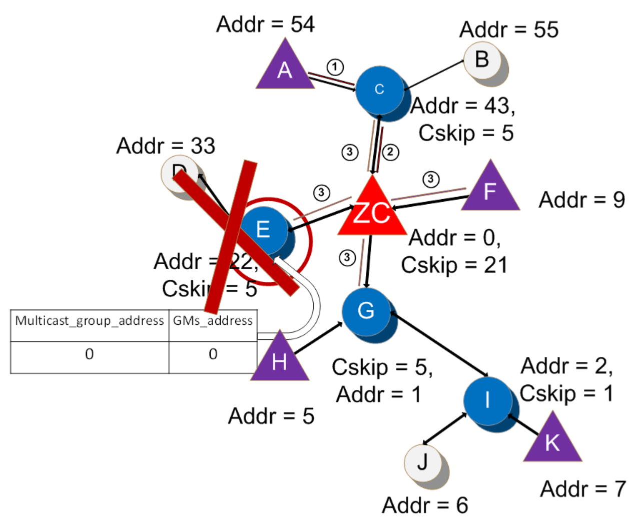

Fig. 7. A non group member discarding the Multicast message

By discarding the packet, all the tree that contains the child nodes of the ZigBee Router *E* will not receive the Multicast packet, which save throughput and reduce energy consumption by avoiding unnecessary transmissions.

The ZigBee End-Device *F* is a member of the Multicast group. The node F receives the packet successfully.

The routing table of the ZigBee Router *G* contains two member nodes, the node *G* retransmits the message to its two child nodes (step 4) as illustrated in Fig. 8.

Thus, the Multicast message reaches the ZigBee End-Device *H* and the ZigBee Router *I*;

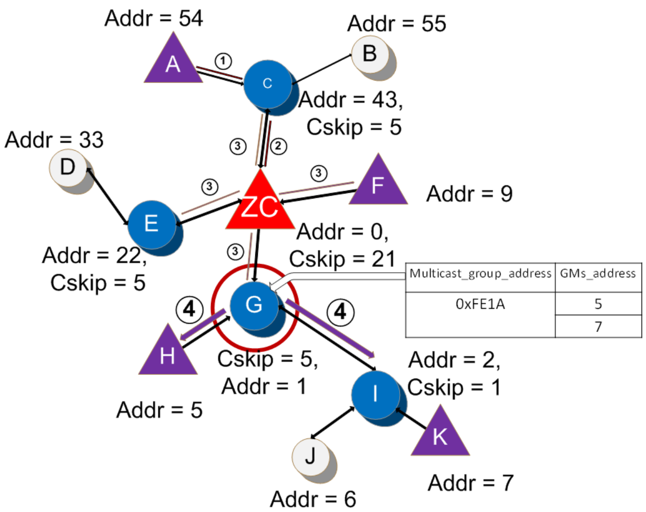

Fig. 8. Router G rebroadcasting the Multicast packet

The ZigBee Router *I* checks its *MRT* and routes the message to the node *I* as it is the only child group member (step 5), as illustrated in Fig. 9.

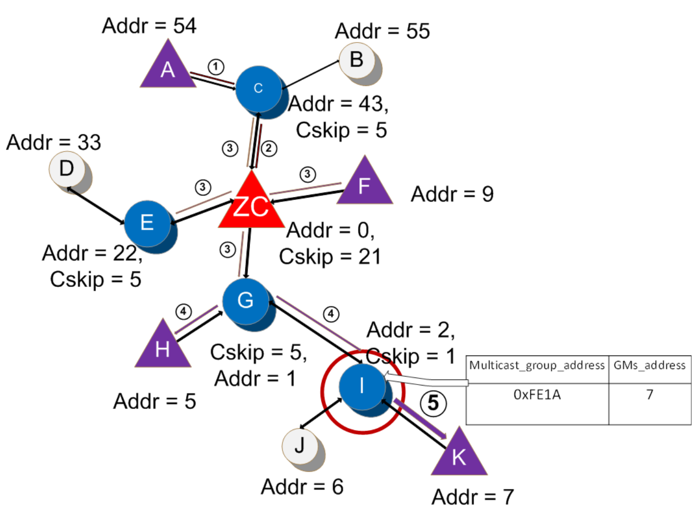

Fig. 9. Router I unicasts the Multicast packet to the group member

Thus, in order to reduce overhead and improve scalability in a ZigBee cluster-tree WSN, the proposed Z-Cast mechanism achieves the following advantages: (1) efficiency of routing the Multicast data through the leafs that contain the group members and thus, the number of messages is significantly reduced. (2) The path between the group members is reduced as every message passes through the ZigBee Coordinator, (3) the message reaches all the group members since all the messages pass through the *ZC*, which has a global view on all the nodes in the ZigBee network .

V. Evaluation and Implementation Issues

A. Analytical Evaluation

In this section, we analytically evaluate the proposed Multicast routing mechanism in terms of memory overhead and communication complexity.

1) Communication Complexity: Communication complexity is measured as the number of messages required to route a Multicast packet to a group of N members. The Z-Cast mechanism considerably minimizes the number of transmitted messages so that the initial packet reaches all group members. To transmit a message from a source node to N members, the mechanism needs to route the packet at first to the ZigBee Coordinator, and then to the leafs that contain the group members according to the Multicast Routing Table.

If the group members belong to the same leaf and are in the same depth in the network, there is a unique message that will pass through the ZigBee Coordinator and the intermediate ZigBee Routers until reaching the group members. Thus, the communication complexity of Z-Cast is reduced when compared to unicast communication which requires $O(N)$ communication overhead. The gain of the proposed mechanism in terms of the number of messages may exceed 50% when compared to unicast routing, mainly when the group contains members that belong to the same leaf in the ZigBee cluster-tree *WSN*.

If there are K groups in the network, where each group has a certain number of members, the communication complexity is independent from one group to another as the groups operate independently from each other.

2) Memory Overhead: Z-Cast does not induce significant memory overhead. It is just necessary to store a table of two columns in each ZigBee Router. The Multicast routing table *MRT* requires a small storage space as each ZigBee Router stores only the membership information of its direct child nodes. By this, we reduce the required memory size for the implementation of the mechanism; this small usage of the memory space satisfies the sensor node requirements.

The memory space required in a ZigBee Router increase as $O(N)$, where N is the number of members of the different groups crossing the router. For a reasonable number of nodes in the network, this memory usage can be easily supported by a typical sensor node.

B. Implementation Guidelines

This section presents some practical considerations for the implementation of the Z-Cast mechanism in IEEE 802.15.4/ZigBee. An important feature of Z-Cast is that its implementation requires minor add-ons to the existing protocol.

The idea consists in classifying the 16-bit ZigBee address into two classes : unicast addresses and Multicast addresses. The value of the high-order 4 bits of the addresses: a value of 0xF (binary 1111) identifies an address as a Multicast address; any other value identifies an address as a unicast address. Each device, upon the reception of a frame, reads the routing information fields (Fig. 10) and checks the destination address.

Octets:2	2	2	1	1	Variable
Frame Control	Destination Address	Source Address	Radius	Sequence Number	Frame Payload
	Routing Fields				
NWK Header					NWK Payload

Fig. 10. Network layer frame format [6]

If the destination address is a unicast address (the four high-order bits are different from to 1111), the ZigBee tree routing algorithm will be applied. If these four bits are set to 1111, it refers to the Z-Cast Multicast mechanism proposed in this paper.

The Multicast routing algorithm should be implemented at the network layer like the cluster-tree routing implementation and should return decision to the MAC layer.

If the routing destination address is a Multicast address, the device must check its Multicast Routing Table to decide if the Multicast packet will be routed to the child devices or will be discarded.

The fifth bit of the Multicast address is reserved to the ZigBee Coordinator *ZC* flag. If the *ZC* has received the m Multicast packet, it sets the fifth bit to 1. Otherwise, this bit remains equal to 0. The Multicast message must be processed by the *ZRs* only if it comes from the *ZC*. Hence, upon reception of a Multicast packet, the *ZR* should check the origin of the Multicast frame. If the packet is coming from the *ZC*, the packet is processed. Otherwise, it will be routed to the parent device until reaching the *ZC*.

VI. Conclusion

In this paper, we have proposed Z-Cast, a multicast routing mechanism that ensures efficient communication between sensor nodes belonging to the same group. We showed that Z-Cast is very appropriate for ZigBee Cluster-Tree *WSNs*. The Z-Cast mechanism guarantees that a multicast message sent from a group member reaches all the group members, while reducing the number of transmitted packets. This is achieved by discarding the messages in the leafs that do not contain group members. We have also demonstrated how to integrate the Z-Cast mechanism in the IEEE 802.15.4/ZigBee protocol stack with only minor add-ons. We have proven that the proposed mechanism is efficient and minimizes considerably the number of messages transmitted between the group members.

We are currently working on the real implementation and validation of Z-Cast with the open source implementations of the IEEE 802.15.4/ZigBee available under TinyOS operating system.

References

[1] S. Lee, W. Su, and M. Gerla, "On-demand multicast routing protocol in multihop wireless mobile networks," *ACM/Kluwer Mobile Networks and Applications*, vol. 7, no. 6, p. 441452, 2002.

[2] J. Garcia-Luna-Aceves and E. Madruga, "The core-assisted mesh protocol," *IEEE Journal on Selected Areas in Communications*, vol. 17, no. 8, p. 13801394, 1999.

[3] M. Mauve, H.Fuler, 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.

[4] P. Ruiz and A. Gomez-Skarmeta, "Approximating optimal multicast trees in wireless multihop networks," *10th IEEE Symposium on Computers and Communications, La Mangua, Spain*, p. 686691, June 2005.

[5] A. Mizumoto, H. Yamaguchi, and K. Taniguchi, "Cost-conscious geographic multicast on manet," *IEEE SECON 2004, Santa Clara, CA, USA*, p. 4453.

[6] A. ZigBee2006specification, "Zigbee document 064112, http://www.zigbee.org/," 2006.

[7] A. Koubâa, M. Alves, and E. Tovar, "IEEE 802.15.4: a federating communication protocol for time-sensitive wireless sensor networks," *Book Chapter in Sensor Networks and Configurations: Fundamentals, Techniques, Platforms, and Experiments, Ed. (N. P. Mahalik), Germany*, November 2006.

[8] ——, "i-GAME: An implicit gts allocation mechanism in ieee 802.15.4," *In Euromicro Conference on Real-Time Systems (ECRTS 2006), Dresden (Germany)*, July 2006.

[9] ——, "A time division beacon scheduling mechanism for ieee 802.15.4/zigbee cluster-tree wireless sensor networks," *19th Euromicro Conference on Real-Time Systems (ECRTS 2007), Pisa(Italy)*, July 2007.

[10] A. Koubâa, R. Severino, M. Alves, and E. Tovar, "H-NAMe: A hidden-node avoidance mechanism for wireless sensor networks," *8th IFAC International Conference on Fieldbuses and Networks in Industrial and Embedded Systems, Ansan, Republic of Kore*, May 2009.

[11] R. Zheng, L. Sha, and W. Feng, "MAC layer support for group communication in wireless sensor networks," *Mobile Adhoc and Sensor Systems Conference, 2005. IEEE International Conference on*, pp. – 395, November 2005.

[12] F. Sun, C.-L. Fok, and G.-C. Roman, "sChat: A group communication service over wireless sensor networks," *Information Processing in Sensor Networks, 2007. IPSN 2007. 6th International Symposium on*, pp. 543 – 544, April 2007.

[13] 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.

[14] A. Sheth, B. Shucker, and R. Han, "VLM2: A very lightweight mobile multicast system for wireless sensor networks," *IEEE Wireless Communications and Networking Conference (WCNC) 2003*, 2003.

[15] B. Chen, K. Muniswamy-Reddy, and M. Welsh., "Ad-hoc multicast routing on resource-limited sensor nodes," *the Second ACM/Sigmobile workshop on Multi-hop Ad Hoc Networks: from theory to reality (REALMAN'06)*, 2006.

[16] S. Wu and K. Candan, "GMP: Distributed geographic multicast routing in wireless sensor networks," *third Sen-*

sor and Ad Hoc Communications and Networks (SECON '06), 2006.

[17] J. A. Sanchez, P. M. Ruiz, and I. Stojmenovic, "Gmr: Geographic multicast routing for wireless sensor networks," *Sensor, Mesh and Ad-hoc Communication and Network, IEEE, Secon 06,Virginia, USA*, 2006.

[18] E. M. Royer and C. E. Perkins, "Multicast ad hoc on demand distance vector (maodv) routing," *Proceedings of ACM MobiHoc01, Long Beach, CA,*, pp. 33–44, IETF Internet Draft 2000.

[19] A. Koubâa, M. Alves, and M. Attia, "Collision-free beacon scheduling mechanisms for ieee 802.15.4/zigbee cluster-tree wireless sensor networks," *7th International Workshop on Applications and Services in Wireless Networks (ASWN2007), Santander(Spain)*, May 2007.

[20] G. Wagenknecht, M. Anwander, M. Brogle, and T. Braun, "Reliable multicast in wireless sensor networks," *Fachgesprch*.

[21] S. Lee, W. Su, , and M. Gerla, "On-demand multicast routing protocol in multihop wireless mobile networks," *ACM/Kluwer Mobile Networks and Applications*, vol. 7, no. 6, p. 441452, 2002.

[22] J. Garcia-Luna-Aceves, , and E. Madruga, "The core-assisted mesh protocol," *IEEE Journal on Selected Areas in Communications*, vol. 17, no. 8, p. 13801394, August 1999.

[23] J. Wu and Y. Tay, "AMRIS: A multicast protocol for ad hoc wireless networks," *IEEE Military Communications Conference (MILCOM-99), Atlantic City, NJ*, pp. 25–29, November 1999.

[24] J. G. Jetcheva and D. B. Johnson, "Adaptive demand-driven multicast routing in multi-hop wireless ad hoc networks," *Proceedings of ACM MobiHoc01, Long Beach, CA*, pp. 33–44, October 2001.