# A POSITIONAL STUDY FOR NETWORK MODELING USING ZIGBEE PROTOCOL

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## ABSTRACT

Zigbee technology makes possible to design a high distance network with low cost, and low communication rate. Mapping and locating of objects is one of the possible approaches of zigbee networks. Our research is based on the intrinsic intelligence of a zigbee network with low rates of transmission however, high efficiency in mapping objects. Our study focused in basic uses cases, for example, tracing certain trajectories. This work is also focused in the location of mobile objects from a fixed device, used for reference sectors within a determined area. Other example shows the location of the objects in the sector that this objects belongs to. Our proposal is to use the prototype tool developed for this study, named TinyBee, in order to validate the tests applied using zigbee nodes and to present their results.

Keywords: Zigbee, Mapping, Smart Grid.

## 1. INTRODUCTION

By making use the methodology exposed in the article [1], this work makes use of a specific algorithm, Signal Strength indicator (RSSI), and another algorithm uses the Quality Indicator (LQI). Both works in parallel mapping the different intensity of such indicators, obtained from the signals of the network nodes.

Due to the nature of the zigbee network it is not necessary the use of an access point for connecting nodes, as it happens in a Wi-Fi networks. On the other hand, routers nodes are used to compose a network. This way a longer distance can be achieved, then, the nodes naturally contribute to compose the network and those same nodes could be used for mapping [2]. However, the zigbee technology is the indicate one for this kind of study.

The zigbee technology was not developed to attend precision criteria, but, in this case it can be used to find the right point in the network. Once the points create the networks, these nodes are fundamental piece in the integrity of such network. However, the replacement of a node by another one not will affect the functioning of the network. The case of reference mapping, such as networks with mobile nodes and fixed nodes as described in the research [3] the not need high precision due to a such mobile node be connected to a one or more fixed nodes, that is possible to find out the locations of this node. In another words, from static nodes distributed in a space with many sectors, the zigbee network itself with no other coupled equipment is capable to yield the location of a mobile object with is in one of those sectors.

### 1.1. THE DIFFERENTIAL

Our goal is to propose a solution to large mapping and harsh environments aiming use a technical system with low cost, high distance of range and high precision. The other options of transponders (RFID - Radio Frequency Identification) or global positioning (GPS – Global positioning System) are enough for this assignment, mostly considering their range. However, in order to add network performance (active transponders) the investment of the project might be over expensive. Added to this, for those cases where it is necessary find devices in indoor places, the GPS could not be applied due the satellite poor functioning with no direct sight.

In conclusion, thinking on the study's relevance, the modernity walks to the point where the basic smart services in environment can be dissociated from the human operability. Therefore, we judge important such study that can to base complex control systems in big operational ambit.

## 2. RELATED WORKS

We have looking for based on inclusion criteria such as "Corporate smart grid", "Enterprise smart grid", in database from IEEEXplore, after, with pre-selected results, we filter searching for, first complete similar words in the articles, how our research proposal has focus in the corporative smart grid, maybe some application must be inside full text it, by citing it, and not in title, abstract or, still, key words, explicitly, 73 papers already have returned. In second moment, we take only researches which are "Conference publication", "Early Access Articles", resulting in 10 papers from there. Therefore, we find 10 related works that use themes like our work. For them results, is important say the time period is from 2011 to 2014, or actually, and for any authors and institutes were considered.

## 3. THEORICAL BASIS – THE NETWORK TOPOLOGY

Due the application design we used the mesh topology, to know, each node could connect itself with any other node within their operation radius. That network's organization leads the natural group making (clusters), where connector's nodes link with neighbors groups [5].

The multiple access protocol used by the network's nodes is the CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance), in other words, before a node send some date it has to "heard" the channel and check if the path is free, then, send a broadcast message to advise all to wait the transmission during a determinate period and does not send any message in the same time, avoiding signal collisions.
According to [5], the most important attribute of the IEEE 802.15.4 standard is its potential to create self-organizing networks capable of adapting to different topologies, connectivity nodes and traffic conditions, thus, its application as well as less costly , allows the network to cover a large area, something up to 65,535 nodes per network. In fact, this pattern contemplates the possibility of being used in real-time applications (real time). The spread of this technology is the quotient between coverage area versus amount invested, so for the same demand, wired networks (Ethernet) or wireless (Wifi, RFID or Bluetooth) have higher costs and lower accuracy.
ZigBee network presents the possibility of multiple links between nodes, function known as multi-hop, due to its training mesh network capability. This configuration allows the quickly removal and addition of other nodes in the network, because each router node has a table which is updated at the lowest cost from this to the destination nodes, with your internal algorithms, Modified Ad Hoc on Demand Distance Vector Z-AODV (Distance Vector) and Hierarchical Routing [6] and [7].

## 4. CONCEPTION AND DEVELOPMENT OF THE PROTOTYPE TOOL

The present proposal was validated by developing and use of a prototype tool. Three different applications were testing in the same zigbee mesh. Such test were splitted in two conception classes, the first one with two steps was classified as Positioning, and subdivided in 1- mapping and 2- location. These tests were pictorially positioned, that is, they measure the location of the target object and its eventual path relative to the network.
By knowing the object it is possible to send data to the fixed devices. Within this context, the second class is denominated by Bi-directional communication, which makes reference to the device communication function. For those tests, the mobile device named by coordinator, could send signal to another node that being part of the mesh creating a communication on both sides.
Were used for these tests some development Texas Instruments kits ZDK (Zigbee Development Kit).
We had tested the CC2530ZNP review 1.0 both for the fixed nodes and the mobile nodes. We had developed a functioning algorithm for each node according their function in the network. The root node is responsible to send commands to the destination nodes and receive data from the fixed nodes. Although, zigbee nodes have different denomination classified between end-points and routers, we decided to work with the roots nodes even to the fixed and mobile nodes. Our focus is to obtain more flexibility in those cases when occur a signal fault of a bridge fixed node some other node could works similar.

### 4.1 ALGORITHM

**A. Fixed Node**
The algorithm bellow integrates the fixed nodes on the mapping, are essential to set the network and intermediate the transmissions between the mobile nodes and the root. At first, the algorithm verifies if there is any message of type 0xA0, if it is positive, sends a message to root that composed by their MAC address and the MAC address of the mobile node.
In addition, this message occurs when some fixed nodes that are in the coverage area of a mobile node received a positioning message. Thus, in the case of it received a message 0xC1 address to this node, so it runs the action. As experimental proposes we just have created an action that works with the device's input and output pin (GPIO – General Purpose Input/Output).
Finally, if the fixed node received any message that exists in the neighborhood, i.e. on their coverage, forward to this interface, if not, sends the message to all interfaces (Method known as Flood).

```
Forever
        If
        has received some message 0 x A0, then
        It sends the address vector to root (0 X C0).
        Else if has received any message 0 X C1, then
        If
        address is the same of the message address,
        then
        Execute the message action.
        Else
        if the address is on the address vector
        then
        forward the message for the relative address.
        Else
        forward the message for all nodes of the
        address vectors.
        End If
End forever
```

**B. Mobile Nodes**
The algorithm bellow runs in the mobile nodes and constantly sends positioning messages (0XA0) to their neighbors, i.e., only those fixed nodes that are within its coverage area. Ignore any other incoming messages. To avoid consuming too much energy we set the ten-second interval for this node send a new position message.

```
Forever
    It sends the message 0XA0 in Broadcast with HOP
    equal 1, i.e. neighbors.
    If
    has received some message then
    Discard message.
    End if.
End forever
```

**C. Root**

This algorithm is essential for network data collection and to interfere in the behavior of the network thus, as in zigbee networks there is only one root node, this algorithm is of paramount importance to mediate the network due to the task that includes: Setting the network unique identifier (PanID), control the access on network by nodes and to restrict non-certified, among others.
On its operation if it receives a message of type 0xC0, i.e. a positioning message from a mobile node forwarded by a fixed node it just writes into COM port (USB) the message to our analysis tool (Tiny Bee) aiming get that message. Conversely, if it receives a message of type 0xC1 - A message of action, it rides a message filling the CMD field, which is the command to be executed, and VALUE for the value to be set, see Figures 3 and 4. After this, sends this message in Unicast to the destination fixed node.

Forever
    If
    has received some message 0XC0
    then
    It sends the address vector of the message to the USB port.
    Else
    if has received some data from USB Port
    then
    set up header 0XC1.
    Understand the type of action and adds necessary information into message.
    Sends message to the relative address.
    End if.
End forever

Figure 1 shows the header protocol developed and used for communication on the zigbee network. It consists of seven fields, the first to indicate the type of message referred to the used types are shown in Figure 3. The two and three fields are the relative addresses for the network to the sender and receiver, that is, each new configuration of a network these addresses are modified, thereby functioning like IP address, i.e dynamic address. The following fields, four and five uniquely identify interfaces of the devices these addresses are static and are not modified at any time so those came from the factory. These addresses works as SSN (Social Security Number) addresses. The CMD and VALUE fields are exclusive of bi-directional communication, i.e., for transmissions in the direction from the root to the nodes, the figure 4 illustrates the variables defined for these fields. Finally, the LQI field is only filled in communications from mobile to fixed and fixed to the root, which is the signal quality indicator which the message was transmitted.

| MESSAGE STRUCTURE | | | | | | | |
|---|---|---|---|---|---|---|---|
| TYPE | SHORT ADDR SRC | SHORT ADDR DEST | MAC ADDR SRC | MAC ADDR DEST | CMD | VALUE | LQI |
| 1 BYTE | 2 BYTES | 2 BYTES | 8 BYTES | 8 BYTES | 1 BYTE | 1 BYTE | 1 BYTE |

| LENGTH |
|---|
| 24 BYTES |

Figure 1 – Structure of the message exchanged between the nodes.

The figure 2 describes the fields of the protocol used in the messages. The column "Memory Type" indicates what type of variable used for this purpose, CHAR type variables store only one byte, with its range of values ranging from 0 to 255 in decimal. The CHAR notation (size) indicates an array of CHARs with the defined size, this way is possible store sequences of CHARs.

| | | MEMORY TYPE |
|---|---|---|
| TIPO: 0XA0 .... 0 XFF | | CHAR (0...255) |
| SHORT ADDR SRC : 0X00....0XFF | 0X00...0XFF | CHAR [2] (0...255) |
| SHORT ADDR DEST : 0X00....0XFF | 0X00...0XFF | CHAR [2] (0...255) |
| MAC ADDR SRC : 0X00...0XFF (8x) | | CHAR [8] (0...255) |
| MAC ADDR DEST : 0X00...0XFF (8x) | | CHAR [8] (0...255) |
| CMD : 0X00 ... 0XFF | | CHAR (0...255) |
| VALUE : 0X00 ...0XFF | | CHAR (0...255) |
| LQI : 0X00 ...0XFF | | CHAR (0...255) |

Figure 2 – Data types of the message

The figure 3 sets out the types of messages that travel over the network, to the functioning of all parts of the network only use three messages, the first to start positioning, from a mobile node to the fixed nodes of their coverage, so it sends the message 0xA0 in broadcast message with the prescription set time for a node at most, and ensures that only the first level of neighbors, direct neighbors, receive the message, so we use the number of hops equal to one.

| TYPE | FUNCTION | PARTICIPANTS |
|---|---|---|
| 0XA0 | START POSITIONING PROCESS | MOBILE NODES TO THE NEIGHBOURS FIXED MOBILE |
| 0XC0 | FORWARD AN ADDRESS VECTOR FOR ROOT | FIXED NODES TO THE ROOT |
| 0XC1 | START THE CATION PROCESS OF PERFORMANCE IN THE NETWORK | ROOT TO THE FIXED NODES |

Figure 3 – Description of the types of messages.

The second type of message is the one used by fixed nodes, identified by 0xC0, and is used to forward the message 0xA0, that is sent by mobile node. Finally,

messages of type 0xC1 depart from the root node in order to perform some action defined by the user at some fixed network node.
Thus, dependent on the fill of the fields six and seven of the message by the user, details on possible commands are present in the figure 4.

| CMD | VALUE INTERVAL | FUNCTION |
|---|---|---|
| 0X01 | 0X00 (OFF) / 0X01 (ON) / 0X02 (BLINK) | TURN ON/OFF THE GPI/O-1 |
| 0X02 | 0X001 / 0X01 / 0X02 | TURN ON/OFF THE GPI/O-2 |
| 0X03 | 0X001 / 0X01 / 0X02 | TURN ON/OFF THE GPI/O-3 |

Figure 4 – Description of the activities of the messages commands.

The figure 4 shows the commands determined to meet the demands of research. However, we include in this step only a small amount of possible commands of the commands. Experimentally we used three GPIO pins on each device that allow only two logical states, on or off, that could control a door, electronic equipment or any other sensors.
However, there is a possibility of entering commands to input signals from external sensors, for example temperature sensors, light, altitude, among others. Or, gradual manipulation of outputs as can be observed in the application of gradually turning on a lamp or control the speed of a rotary engine and so on.
We use the codes 0x01, 0x02 and 0x03 to control signal outputs, in order to activate or deactivate leds (light-emitting diodes) to light declare the code 0x01 and 0x00 to delete the code.

## 5. TESTS

Tests were split in three categories in order to evaluate possible solutions provided by zigbee grid and managed by zigbee. In all tests we made use of our prototype. Tests were organized to balance both sides: the side of the grid itself, and the user side. The first test evaluates the passive capability of the network, that is, the grid informs the user its state. The second one evaluates the active capability of the network, that is, the user has the power to change the behavior of the network by sending commands. The last test evaluates mesh “intelligence”, by verifying if users stimulus (actuation logic) change mesh behavior after any action. The first test stores only the answers of trajectory points of the object. The second test adds the knowledge of object location inside the mesh, registering the last information.
Three different configurations were tested involving mapped objects that should be tested and zigbee devices.
Our proposal was validated by the use of our prototype. Tests executed using real sceneries and the developed tool are the following: location of portable objects using fixed objects as reference, mapping routes of portable objects using fixed objects as reference, modeling smart grids zigbee with actuators and physical sensors. For each one of these tests a certain sequence of steps was performed in order to evaluate points of interest and achieve expected results. In each of the tests performed, the composition of results, efficiency and accuracy was enough to measure the applicability of such proposition, i.e., our goal was reached when apply the real tests.
All of the fixed nodes were physically positioned and located by the tool before the beginning of the tests in order to optimize them. This is not a required step once the grid is adaptable to new node inputs and outputs, a characteristic which is a factory guarantee defined a priori in zigbee devices.
The figures 5 and 6 show devices and sensors used for tests and validation of our proposal. Devices used in the tests include: 15 Target Board CC2530ZNP devices from Texas Instruments, 13 of them set with fixed node, 1 with portable node and 1 with root node, 1 notebook and TinyBee validation tool.

Figure 5 - Devices used for field tests.

Figure 6– One of the fixed nodes used in the field tests.

Test 1 – Passive Capability: capture or track the position of a portable node, that is, the places the node passed by.

Figure 7 was captured from the analysis tool as a result of a test with three fixed nodes and 1 portable, by moving the portable node through the coverage area of the static nodes.
Figures 8 and 9 shows the result of mapping a portable node that moved from FF299-BF4DE-854CC to north. It was detected that as the portable node leaves the coverage area of fixed points BF4DE and 854CC, the node was connected only to FF299 node, later it belonged to 64FF0-B14DC-FF299.


Figure 7 – Passive test with three fixed nodes.

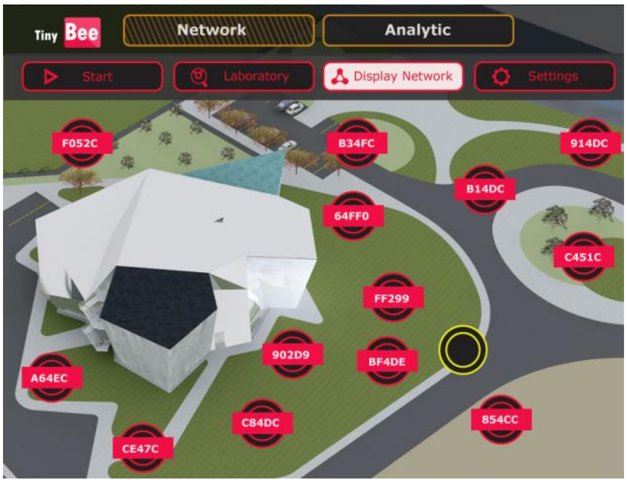


Figure 8– Passive test with thirteen fixed nodes.


Figure 9 – Passive test with thirteen fixed nodes.

Test 2 – Active Capability: Choose any node and send a signal to it, when the chosen node receive the signal, it should lights its own led (light emitting diode), as shown in the figure 10.

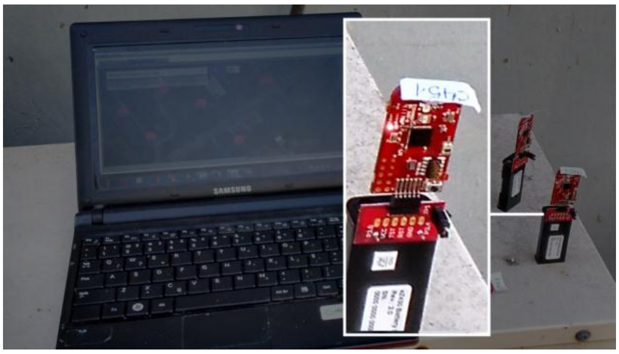

Figure 10 – Active test to one fixed node

Test 3 - Cognitive Capability: Choose any fixed node and inject the logic to recognize the proximity of a portable node and lights up the led. (Figure11)

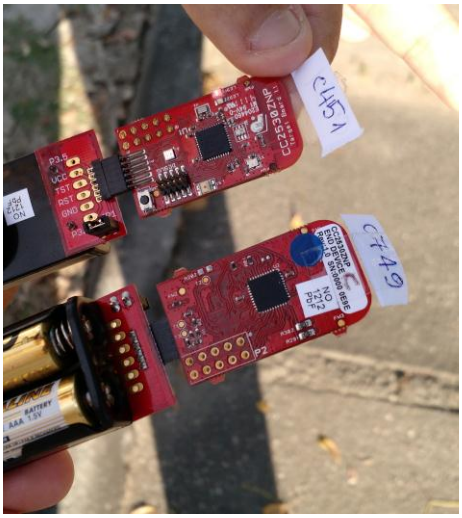


Figure 11– Actuators on fixed node test.

All the tests can be repeated and verified by users. For this purpose it is necessary to have three zigbee devices, model CC2530ZNP and our tool, containing source codes related to internal nodes functioning (low level information) and the validation prototype that can be obtained by sending us an e-mail.

## 6. RESULTS – PERFORMANCE ANALYSIS

We based our evaluation in three techniques of system performance, modeling, simulation and measure [7]. By the use of these techniques we built hybrid models that assures higher confidence in evaluation results pointed by virtual maps that represents individual positioning of physical nodes. For modeling, we designed a support tool that allows understanding and projection of dynamic grids, considering aspects of mapping dimension, coverage area, and efficiency.
Simulation was conducted using this tool and some mobile and fixed nodes, in order to evaluate the integration of our tool with the devices simulating a high scale mesh. Last but not least, we ran some tests to verify nodes capabilities of mapping and positioning, for which we use our tool to validate tests.
In order to improve confidence in conclusions obtained this sample should represent the observed system. The

bigger is the sample, the better the representatively. However, if the sample becomes too big, it will demand increasing resources and effort.
The equation (I) describes the minimum size of the sample (number of tests or experiments).

$$n = \frac{Z^2 . \alpha^2}{E^2} \qquad \text{(I)}$$

Z = Confidence level
α = Sampling average
E = Possible sampling error arbitrated by the analyst

We use the value 70% for confidence level, even in laboratory tests, there are obtained the effects of interference. The sample average chose the number five to map the desired land, something about 1200 $m^2$ (one thousand two hundred square meters) that are 30m by 40m wide, as each zigbee node covers about 7 meters radius, the average can be 13 us fixed, i.e., the total area ($13 \times 49 \times \Pi = 2.001 m^2$) is sufficient to map the target area. For sampling error, we consider only one node in the worst case at most one node can be lost. Thus, we have the minimum number of experiments that must run in the field to validate our tests, according to equation (II):

$$n = \frac{0{,}7^2 . 5^2}{1^2} \qquad \text{(II)}$$

$$n = 13 \text{ tests on network}$$

## 7. FUTURE WORKS

Complementarily, we realized that this research offers some extra features that could be added. For example, in order to manage the date collected, three diagrams should be generated. The first one is to get the overview of the fixed nodes frequency on the indicated zones. Thus the accesses numbers of the mobile nodes are delivered by the fixed nodes. A layout suggestion could be seen on the figure 12.

The figure 13 is the visual demonstration using graphic elements of the figure 12 and let us easily observes the movement of the mobile nodes by the fixed nodes zone, i.e. such zones that presents more population of mobile nodes. This diagram could be used as a tool to analyze such POS (point of sale) that attracted more consumers.

The figure 14 shows a tracking proposal of a specific mobile node in the fixed zones. It leads us to observe the temporal displacement of the node and should be applied to optimize the internal process of the companies as FedEx and telegraph.

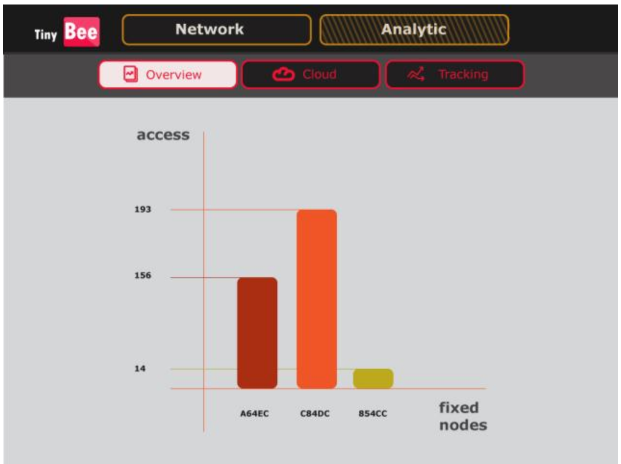


Figure 12– Mobile access for fixed areas.


Figure 13– Mobile access distribution for fixed areas.

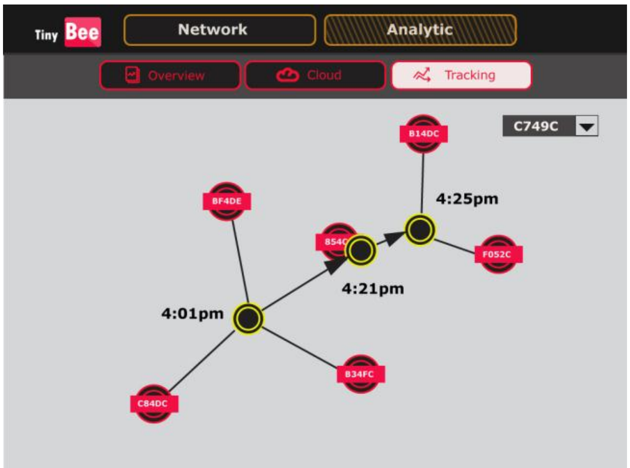


Figure 14– time tracking of mobile nodes for fixed areas.

## 8. CONCLUSION

The prototype tool plus the algorithm developed to operate in nodes of a zigbee network drove the field tests aiming to evaluate their functioning above uncontrolled situations. As well, we aimed to test the capability of the

zigbee network of work in a mesh grid providing more robustness and a great range of functions which could be adapted to current situations of a company. As a result of these tests we could verify the zigbee network adequacy of providing services control and assets management by inputting automatic settings.
In addition, we could note it will not face difficulties to adapt to different scales of network's design since the zigbee network makes the reach higher due their great scalability. Finally, we intend that this study could support future research as a base content.
Consequently, the composition of results and efficiency were sufficient to measure the applicability of proposition, which the use cases are based on bias of theoretical study.

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